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Revegetation Information Applicable to Mining Sites in Northern Canada

Everett B. Peterson and N. Merle Peterson
Western Ecological Services Limited

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REVEGETATION INFORMATION APPLICABLE TO MINING SITES IN NORTHERN CANADA

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REVEGETATION INFORMATION APPLICABLE TO MINING SITES IN NORTHERN CANADA: SELECTED REFERENCES

by N. Merle Peterson

INTRODUCTION

This annotated bibliography summarizes published information on revegetation techniques that could be applied to reclamation of disturbed surfaces created by mining in the Yukon and Northwest Territories. This section is the reference source for a much shorter "state-of-the-art" review entitled *Suggested Approaches to Revegetation of Mining Sites in Northern Canada* on pages *viii* to *xxii*. The shorter review is intended for use by resource management officers or mine managers who must make policy decisions on where, when or if assisted revegetation is to be attempted on disturbances resulting from mining activities in northern Canada. In contrast, this detailed bibliography is intended more for those who must put into practice a policy decision to provide assisted revegetation to a disturbed land surface. The annotated references, with the aid of two indexes, provide a considerable number of suggestions on what to do to accomplish revegetation, and how and when to do it, for anyone responsible for assisted revegetation of disturbed surfaces in the Yukon or Northwest Territories.

HOW TO USE THIS BIBLIOGRAPHY

Even the most devoted revegetation specialist is unlikely to read this bibliography progressively from start to finish. It is not intended to be read as one would read a book. The key to its use is the indexing system and readers are advised to rely on the two indexes to find information of interest to them.

The first index (pages 393 to 399) is a subject matter classification of information contained in the annotated references. This subject index is not arranged alphabetically; it is organized approximately according to a chronological sequence of steps that one would follow during a program of assisted revegetation. Such a sequence would begin with the basic decision on whether assisted revegetation is an appropriate goal for the area in question. The next logical steps are to understand the objectives sought by assisted revegetation, the factors limiting revegetation, and some of the documented revegetation successes and failures on industrially disturbed sites. With such an understanding, the reclamation officer can proceed to decisions on choice of revegetation species, revegetation methods, and timing of revegetation steps. At the end of this chronological sequence, the subject matter index includes, on pages 398 and 399, some additional categories such as revegetation costs, interactions between animals and assisted revegetation, unassisted revegetation of disturbed areas, the time scale involved in revegetation, and research needs.

The second index deals with northern disturbed areas to which existing revegetation knowledge is thought to be applicable; it is not an index of areas in the North from which revegetation information has been collected. In this index, the Northwest Territories and Yukon are divided into eight ecologically distinct regions, as shown in Figure 1 of this report. The eight ecological zones shown in Figure 1 are taken from the *Land Use Handbook, Guidelines to Assist in the Application of the Territorial Land Use Regulations*, Department of Indian and Northern Affairs, with three modifications: (1) no distinction was made between sedimentary and Precambrian areas in the Canadian Arctic Archipelago so that this entire archipelago is shown as one region (area 1); (2) the mainland boreal region in the Mackenzie District is subdivided into a separate region called "Southwestern Mackenzie" (area 5) which is the area south of the zone of widespread permafrost; and (3) the northern Yukon (area 6) and southern Yukon (area 8) are distinguished from each other and from the boreal portions of the Mackenzie District (area 4). For each of these eight regions, three general kinds of disturbances related to mining (overburden, roads, and tailings) are recognized. For purposes of this index, roads include any other disturbances that involve only surface disruption of drainage, vegetation, organic matter and mineral soil, such as sites for exploratory diamond drilling or plant sites. Overburden is meant to include more substantial disturbances below the mineral soil horizons and could include waste rock, adit wastes, coal reject dumps, spoil piles, and material excavated from exploration trenches.

This index of applicability to northern areas identifies the pages in this bibliography that contain references of most use to someone interested in revegetation of a particular kind of disturbed site (overburden or road or tailings) in a particular region of the Yukon or Northwest Territories. For example, someone interested in revegetation of overburden in the Arctic Islands may find useful information or ideas on various pages in this bibliography, but the references of most relevance and the ones that should be checked first are the page numbers listed for overburden in the Arctic Islands region (pages 9, 10, 15, 17, 209). In this example it will be noted that these listed references are not necessarily a description of revegetation of overburden in the Arctic Islands; they are simply the sources of information that were judged to be most applicable to revegetation problems on overburden surfaces in that region.

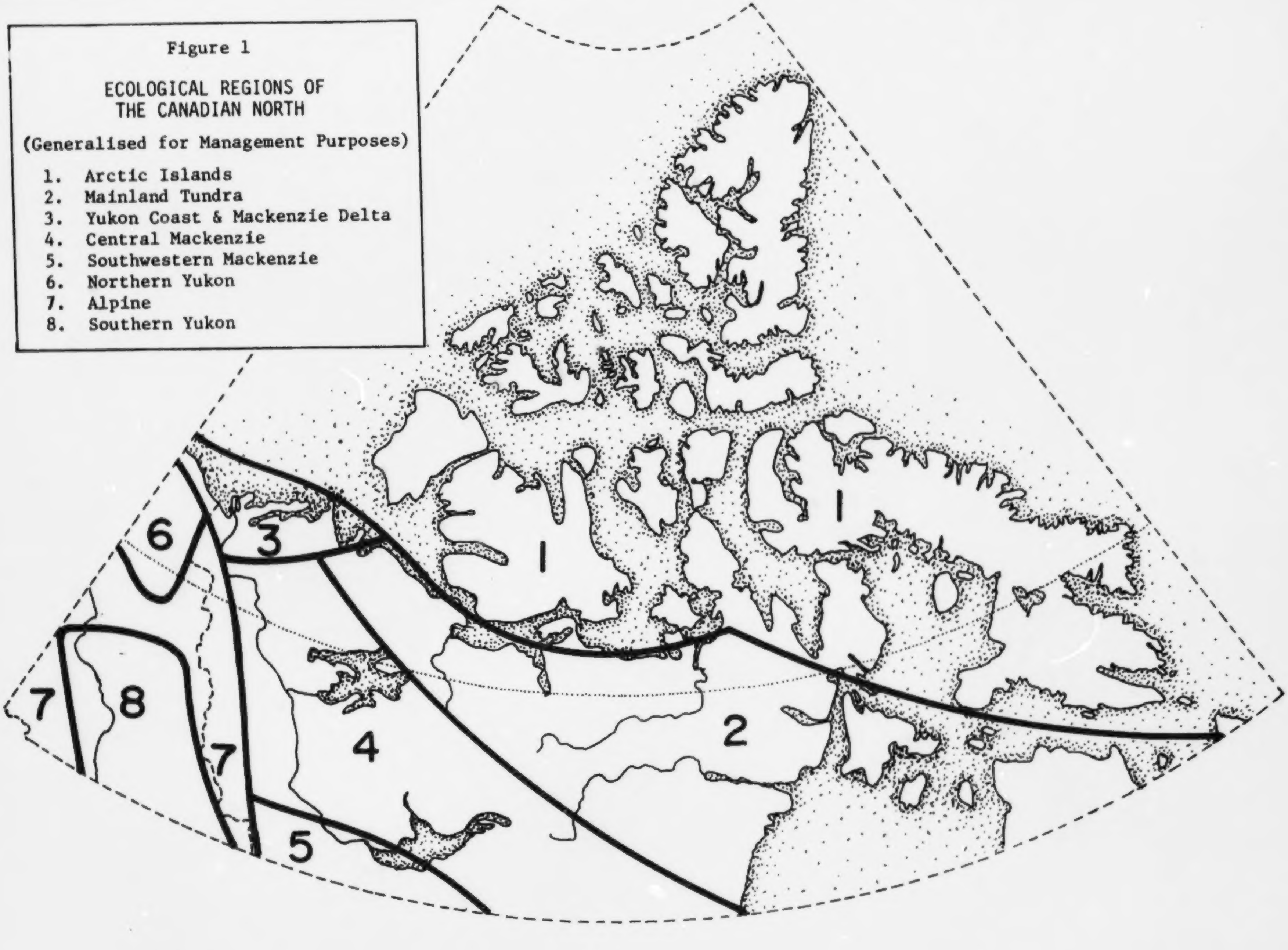

Figure 1

ECOLOGICAL REGIONS OF THE CANADIAN NORTH

(Generalised for Management Purposes)

1. Arctic Islands
2. Mainland Tundra
3. Yukon Coast & Mackenzie Delta
4. Central Mackenzie
5. Southwestern Mackenzie
6. Northern Yukon
7. Alpine
8. Southern Yukon

SCOPE AND FORMAT OF THE ANNOTATIONS

GEOGRAPHIC SOURCES OF REFERENCES

There are very few published accounts of natural or assisted revegetation on Yukon or Northwest Territories mining sites. Therefore, the literature search included revegetation articles from other areas, with greatest emphasis on those from Alaska, Alberta and British Columbia. Selection of references applicable to northern mining sites and selection of the most relevant material from the chosen references was a matter of judgement that was guided by the following criteria:

- revegetation reports from study areas ecologically similar to portions of the Yukon and Northwest Territories were annotated in respect to both botanical and physical details;
- revegetation reports from study areas ecologically different from any sites that could be encountered in the Yukon or Northwest Territories were annotated mainly in respect to physical aspects of reclamation.

For example, an article on species suitable for revegetation of alpine areas in the Peace River Coal Block of northeastern British Columbia mining sites would be annotated in considerable botanical detail because of the ecological similarities with the Yukon; an article on species suitable for revegetation of Pennsylvania coal mine sites would not be annotated unless it contained transferable information on techniques. In general, references from southern Canada, United States or Europe were annotated only if they provided information on physical phenomena that one could expect to find in the Yukon or Northwest Territories.

The geographic origin of each reference is indicated in item 6a of each annotation, by means of political place names and generalized ecological zones (for example, British Columbia, Rocky Mountains). Of the 223 selected references in this volume, 113 were derived from studies in Canada, 87 from the United States, and 23 from other countries. The geographic origin of these references, in decreasing order, is as follows:

Alaska	56
Alberta	31
Mackenzie District	30
British Columbia	18
Ontario	10
Yukon	8
United States (nation-wide)	7
Queen Elizabeth Islands	6

Canada (nation-wide)	6
Colorado	6
Wales	5
England	5
World-wide	4
Scandinavian countries	4
U.S.S.R.	3
Quebec	3
Montana	3
Utah	2
Washington	2
Kentucky	2
Keewatin District	1
Idaho	1
New Jersey	1
Ohio	1
Virginia	1
West Virginia	1
North Dakota	1
Michigan	1
Pennsylvania	1
Wisconsin	1
Eire	1
New Zealand	1

SUBJECT MATTER COVERAGE

As indicated in the subject index on pages 393 to 399, the selected references focussed on the relatively narrow subject of revegetation rather than the broader range of subjects included in the terms "reclamation" or "restoration". The physical steps involved in reclamation, such as methods of materials handling during mining operations, were not included here. However, some references that dealt with physical steps more directly related to revegetation, such as contouring to achieve stable slopes or physical preparation of seedbed surfaces, were included. The emphasis throughout, however, is upon the process of revegetation itself.

Because of the small number of published accounts of revegetation on northern mining sites, the selected references also included examples of assisted revegetation of other kinds of disturbed surfaces in the North, such as seismic lines, rig sites, roads, or test pipeline berms.

Revegetation was interpreted broadly to include both natural and assisted revegetation. There were two reasons for this. First, in regions where agricultural land uses are not an objective for revegetated surfaces, encouragement of the return to a stable, self-sustaining plant community is a widely accepted objective. Thus, a knowledge of the processes involved in natural revegetation of disturbed surfaces can be used to design appropriate assisted revegetation steps that, for various reasons, may be undertaken as interim measures. The other reason why natural revegetation is important derives from the fact that some of the most obvious local sources of plants for revegetation are populations that grow on relatively young moraines, rocky alpine surfaces, or coarse alluvium. Because attempts at assisted revegetation are so recent in the North, it is necessary to look to natural revegetation on disturbed surfaces of known age to derive ecological information on long-term trends. Consequently, a number of selected references deal with processes of natural plant succession, in the belief that these documented cases contain lessons for further development of assisted revegetation techniques.

The relatively large literature dealing with forest regeneration in the taiga regions of Alaska and Canada was not included because there are few ecological similarities between surface disturbances created by mining activities and surfaces created by logging or forest fire.

FORMAT OF ANNOTATIONS

Annotated references appear in this volume alphabetically by author. Each annotation appears in a standard format as follows:

1. Author
2. Date
3. Title of article
4. Where published
5. Source of annotation ('Original' if annotated by N.M. Peterson; 'Author's abstract', 'Dissertation Abstracts' or some similar notation if not originally annotated)
6. Indexing (see explanation below)
7. Annotation

It was assumed that most users of this bibliography would not have access to libraries with comprehensive collections of revegetation literature. Thus, annotations were presented in considerable detail to reduce the need for users to consult the original publication. In each annotation, the emphasis is on results, conclusions and recommendations contained in the original report. Because this bibliography is being prepared for an assumed audience of resource managers rather than scientists it was assumed that users would not need details of experimental design or study methods employed during the original research.

INDEXING

Item 6 of each annotated reference contains two parts. Part (a) contains geographic identifiers to indicate where the original study was conducted, as outlined on Page *iv*. These geographic identifiers have not been compiled into an index at the end of this volume. Therefore, it is not possible for a user to go to an index to identify all of the references that were derived from Alaska, or Alberta or Wales.

Part (b) of item 6 identifies the region of the Yukon or Northwest Territories, and the type of mining-related disturbance, to which the annotated information is judged to be applicable. Details of this part of the index were outlined on Page *ii*.

REFERENCE SOURCES

All selected references are publicly available in library collections. There are some known additional sources of information on northern revegetation experience, such as some proprietary reports of the Alyeska Pipeline Service Company; such sources of information could not be included here but the main findings of such studies are already incorporated into other recent reviews such as that prepared by Younkin, 1976, *Preliminary pipeline revegetation specifications for the Mackenzie Valley region, N.W.T.*

Source libraries were: Library, Boreal Institute for Northern Studies and Cameron Library, University of Alberta, Edmonton; Library, Northern Forest Research Centre, Edmonton; Library, Canadian Wildlife Service, Edmonton; Library, Alberta Department of Environment, Edmonton; Library, Alberta Department of Energy and Natural Resources, Edmonton; Library, British Columbia Department of Mines and Petroleum Resources, Victoria; MacMillan Library, Faculty of Forestry, University of British Columbia, Vancouver; Library, Pacific Forest Research Centre, Victoria; Library, Department of Indian and Northern Affairs, Ottawa and Yellowknife; Library, Scott Polar Research Institute, Cambridge, England; and Library, Department of Environment, London, England.

ACKNOWLEDGEMENTS

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All annotations were edited by Everett B. Peterson. His advice, assistance and encouragement are particularly acknowledged. Production of the final typescript was the responsibility of Glenda Mersky and Shirley Robinson. Special acknowledgement is given for their care and efficiency in this large task.

SUGGESTED APPROACHES TO REVEGETATION OF MINING SITES IN NORTHERN CANADA

by Everett B. Peterson

OBJECTIVES OF THIS REVIEW

This 16-page review outlines principles to guide decisions on where, when and if one should assist the return of vegetation to areas disturbed by mining in the Yukon and Northwest Territories. The purpose is to provide advice to resource management officers or mine managers who must make policy decisions about assisted revegetation of disturbed terrain. The discussion of specific topics in this review is very brief. Anyone wanting details on a given topic can find more information by using the portions of the subject index (pages 393 to 399) that are mentioned in any given paragraph of this review. In the sections below, specific points are referenced to pages of the accompanying annotated bibliography by use of a page number in brackets. More general principles, if not referenced to specific page numbers, are referenced to the appropriate section of the subject index, with notations such as (Index, Sec. 6.1), to allow the interested reader to follow up on more detailed reading.

This review discusses topics in a sequence similar to the steps that one would follow during a program of assisted revegetation, beginning with the basic decision on whether assisted revegetation is an appropriate goal for the disturbed site in question. However, this review does not provide a step-by-step summary of every one of the headings and sub-headings that appear in the subject index. The focus instead is on general principles of importance to those responsible for policy decisions. It is left to the persons responsible for field operations of a revegetation program to delve into the details shown in the subject index and in the accompanying 390 pages of reference material.

WHAT IS ASSISTED REVEGETATION?

This review refers to both assisted and unassisted revegetation. Assisted revegetation involves one or more deliberate steps by man to encourage the re-establishment of vegetation on a disturbed surface; unassisted revegetation refers to natural re-invasion of plants onto surfaces that have been disturbed by either natural or man-made causes.

Some authors have taken revegetation to mean simply the quick provision of plant cover for erosion control (69). In the North, it is necessary to think of revegetation as something more than an erosion control technique. This is especially true as more and more revegetation specialists come to recommend that a prime goal of assisted revegetation is to encourage a stable, self-sustaining plant cover (371,373).

For this review, "revegetation" was interpreted to include a fairly broad range of goals and procedures, but not so broad to include all of the physical steps involved in "reclamation" or "restoration". Various physical steps, such as contouring to achieve stable slopes or preparation of suitable seedbed surfaces were considered to be reclamation steps but were not taken as part of the definition of assisted revegetation. As explained on page *v* some of these physical steps, if clearly related to revegetation procedures, were reviewed from the available literature even though they were not defined as part of "revegetation".

The emphasis here is on revegetation of surfaces on which vegetation has not previously grown. For example, an area where vegetation has died from smelter fumes would have revegetation challenges different from those discussed here. As indicated on pages *iv* to *vi* of this report, the literature reviewed is drawn from a rather wide range of natural and man-made disturbances. It is only in the *interpretation* of this existing knowledge that there has been a rather rigid attempt to limit it to assisted revegetation problems that one would expect to find on surfaces exposed by mining in the Yukon and Northwest Territories.

REVEGETATION IN THE NORTHERN CONTEXT

It is for administrative, rather than ecological, reasons that all the Yukon and Northwest Territories are the focus of this review. In terms of revegetation goals and the chances for successful revegetation, there could be more differences between a spoil pile in the southern Yukon and a spoil pile on Little Cornwallis Island than there would be between the southern Yukon and Elliot Lake, Ontario. Quite possibly, the only point in common between the High Arctic and southern Yukon spoil piles would be their lack of vegetation cover immediately after the spoil was laid down. In the absence of severe toxicity or drought, the southern Yukon spoil pile would be a likely candidate for natural invasion by a number of native plant species; the chance of unassisted revegetation of a spoil pile on Little Cornwallis Island would be virtually nil. Assisted revegetation in the southern Yukon could be expected to have as much chance of success as in British Columbia or at Elliot Lake; assisted revegetation of a spoil pile in the High Arctic would be a questionable venture from an ecological point of view.

The map in Figure 1 shows ecological regions of the Canadian North, generalized for management purposes. This map was the basis for a second index (402-405) that groups available information in terms of its applicability to various ecological zones in the North. This map and index were included to emphasize that the Yukon and Northwest Territories should not be viewed as one area as far as revegetation is concerned. Readers will note that a large number of existing revegetation reports were judged to be applicable to disturbed sites in the southern Yukon and southwestern Mackenzie, which are areas south of the zone of widespread permafrost. Relatively few revegetation reports are applicable to overburden or tailings in other ecological zones of the Yukon and Northwest Territories. This index shows what an observant field inspector or reclamation planner would already know: there is a considerable amount of southern revegetation experience to draw upon and to apply to those parts of the North that are ecologically similar to subarctic regions south of 60°, but there is little revegetation experience obtained directly from overburden or tailings areas within the permafrost zone. Insofar as roads are an integral part of mining operations, they would be an exception to this generalization. Revegetation of roads and other less severe disturbances, where there is likely still a mineral soil cover on the surface, can benefit from a relatively large amount of existing information because a high proportion of northern revegetation studies have been conducted on areas less drastically disturbed than overburden or tailings.

The index of applicability to northern areas (402-405) implies that those faced with revegetation of tailings in the North will have abundant opportunities for pioneering work because little relevant information exists. Those concerned with revegetation of mining roads have a considerable amount of existing northern revegetation experience to draw upon. Those involved with revegetation of overburden can apply much of the information to the southern Yukon and southwestern Mackenzie regions but not very much to other areas north of 60°.

The oldest documented cases of assisted revegetation in northern Canada are only six years old (373). Longer records are available for natural (unassisted) revegetation of disturbed areas (Index, Sec. 11.2). Much of the information about revegetation with native species has been derived from studies of natural succession in arctic and subarctic regions. The most publicized feature of these studies is that recovery is increasingly longer as one progresses northward. Although considerable plant cover can be obtained in 1 to 10 years in many arctic sites, rates of succession in the High Arctic are even lower, with little growth evident after 10 to 20 years. It is estimated that, for much of the Arctic, restoration of the original vegetation and drainage patterns could require hundreds or thousands of years (165). In general, revegetation in the North will take time and there are few, if any, steps that can be taken to hasten it.

Another widely publicized northern feature is the presence of ice-rich soils in certain areas. Goals for revegetation have often been tied to the presence or absence of permafrost, in the view that revegetation will help to restore a permafrost condition in disturbed soils. There is increasing debate over this point because several recent studies have demonstrated that re-grassing is no cure for thermal erosion (37, 142, 162, 371). Ice-rich soils create another kind of problem, too, for revegetation because there is evidence that serious terrain damage results from re-use of stabilizing sites. Plant species that are adapted to the wet soils of ice-rich areas seem to be very intolerant of disturbance, so that a second round of disturbance can be particularly damaging (313). This precautionary note would apply to any disturbed surfaces that involved wet, ice-rich areas but would be less of a problem in any dry overburden or tailings surfaces that were being revegetated. Other studies have shown that thaw and associated problems on disturbed sites are much less important in more northerly arctic regions than they are in the Low Arctic. In the High Arctic, even relatively dense vegetation has a canopy and moss layer too sparse to strongly influence the amount of energy actually reaching the soil (10).

A PRACTICAL LIBRARY FOR THE NORTHERN REVEGETATION WORKER

There are a number of "how-to-do-it" guidebooks available for the bookshelf of the revegetation officer. For the North, the two most useful references would be *A vegetative guide for Alaska* (328), published by the Soil Conservation Service, United States Department of Agriculture, and the *Alaska revegetation workshop notes* (104, 138, 190, 217, 292 and 311), published by the Cooperative Extension Service, University of Alaska. Ways to achieve some of the specific steps of revegetation can be followed up by use of the subject index (Sec. 6), with information ranging from engineering methods for control of erosion (121) to methods of mass producing plantable aspen suckers (391). Although there is a fairly wide selection of publications dealing with revegetation methods, it is still safer to adopt a "results-oriented" approach instead of a "methods-oriented" approach. This has been stated in another way by those who stress that revegetation programs must remain as flexible as possible in order to take advantage of new information and methods as they develop (382). No handbook will likely ever exist to cover the full range of conditions that could be expected on northern mining disturbances.

If one were responsible for development or inspection of a revegetation program in the Yukon or Northwest Territories, and if no revegetation literature was at hand, the highest priority articles, reports and books to obtain for a small practical library would be:

1. *A vegetative guide for Alaska* - See page 328 of this bibliography. Available from: Cooperative Extension Service, University of Alaska, 1512 South Cushman St., Fairbanks, Alaska. The second edition of this guide, to be published in 1977, will contain significant new information on use of woody species.
2. *Revegetation in arctic and subarctic Alaska. A literature review.* See page 161 of this bibliography. Available from: Cold Regions Research and Engineering Laboratory, Corps of Engineers, U.S. Army, Hanover, New Hampshire.
3. *Revegetation studies in the northern Mackenzie Valley region.* See pages 371, 373, 377, 379 of this bibliography. Available from Canadian Arctic Gas Study Ltd., 1270 Calgary House, 550 - 6 Ave. SW, Calgary, T2P 0S2.
4. *Revegetation studies - Norman Wells, Inuvik and Tuktoyaktuk, N.W.T. and Prudhoe Bay, Alaska.* See page 141 of this bibliography. Available as Report 72-73-14 from: Arctic Land Use Research Program, Department of Indian and Northern Affairs, Ottawa K1A 0H4.
5. *Alaska revegetation workshop notes.* See pages 104, 138, 190, 217, 292 and 311 of this bibliography. Available from: Cooperative Extension Service, University of Alaska, 1512 South Cushman St., Fairbanks, Alaska.
6. *Licensed varieties of cultivated grasses and legumes.* See page 101 of this bibliography. Available from: Information Division, Canada Department of Agriculture, Ottawa, K1A 0C7
7. *Seeds of woody plants in the United States.* See page 291 of this bibliography. This handbook replaces the former *Woody plant seed manual* and is available from: United States Department of Agriculture, Forest Service, Washington, D.C.

8. *Inventory of Canadian revegetation practice.* See page 270 of this bibliography. Available as Supplement 10-1 of the CANMET *Pit slope manual* from: CANMET, Department of Energy, Mines and Resources, 555 Booth St., Ottawa, K1A 0G1.

9. *Guidelines for coal and mineral exploration.* See page 284 of this bibliography. Available from: Inspection and Engineering Division, Ministry of Mines and Petroleum Resources, Victoria, British Columbia.

10. *Proceedings of the inaugural meeting, Canadian Land Reclamation Association, December 1975.* See pages 12, 61, 106, 205, 300, 324 and 388 of this bibliography. Available from: Crop Science Department, Ontario Agricultural College, University of Guelph, Guelph, Ontario. The Canadian Land Reclamation Association will hold annual meetings and plans to publish future proceedings and a journal dealing with Canadian reclamation experience.

11. *Proceedings of a workshop on reclamation of disturbed lands in Alberta.* See pages 69, 123, 134, 211, 224, 225, 229, 241 and 299 of this bibliography. Available from: General Services Division, Alberta Environment, 14th Floor, Oxbridge Place, 9820 - 106 St., Edmonton, T5K 2J6.

There are two additional handbooks, recently translated from German texts. The first of these is a *Handbook of landscape care and nature protection*, published in German by K. Buchwald and W. Engelhardt, from which an English translation has been prepared by the Alberta Environment Conservation Authority, 2100 College Plaza, Tower 3, 8215 - 112 Street, Edmonton, T6G 2M4. The second is *Sicherungsarbeiten im Landschaftsbau*, [Remedial methods in landscaping], from an original text by H.M. Schiechtl, translated for the Research Secretariat, Alberta Environment, 14th Floor, Oxbridge Place, 9820 - 106 Street, Edmonton, T5K 2J6.

Many of the existing reclamation bibliographies and "state-of-the-art" reviews pertain to the United States. If anyone wishes to complement this volume with other reviews or bibliographies, the most useful references for northern revegetation work would be those by Donavan (90), Johnson and Van Cleve (161), Murray (270), Younkin (373), and Zasada (382). For high-altitude disturbed lands, two excellent references are available from the Environmental Resources Centre, Colorado State University, Fort Collins, Colorado, 80523. These are: *Proceedings of a workshop on revegetation of high-altitude disturbed lands* (see pages 25 and 97 of this bibliography); and *Bibliography pertinent to* *disturbance and rehabilitation of alpine and subalpine lands in the southern Rocky Mountains*, by O. Steen and W.A. Berg, Information Series No. 14, Environmental Resources Centre, Colorado State University, 1975.

IS ASSISTED REVEGETATION A VALID GOAL ON ALL NORTHERN MINING DISTURBANCES?

In southern Canada, it is generally a foregone conclusion that assisted revegetation will be a part of reclamation, although the revegetation supplement of the *Pit Slope Manual* provides criteria to evaluate whether alternatives to revegetation should be considered (271). The admission that under certain circumstances in southern Canada revegetation may not be an appropriate goal suggests that this could be a particularly important question in the North where there are even more factors limiting revegetation than there are in the South. The subject index (394) identifies several references that touch on the question of whether assisted revegetation should be attempted for a given area.

To begin with extreme examples from the High Arctic, the Beaufort Formation of the northwestern Queen Elizabeth Islands or the Christopher Shale on Melville Island are surfaces that support little if any natural vegetation. A program of assisted revegetation would be difficult to justify economically, ecologically or even aesthetically for disturbances on these normally barren surfaces (39). In addition to high arctic sites, there may be extremely dry areas or certain wastes with chemical or physical properties that prevent revegetation (5). In such situations, physical or chemical sealants will be better than assisted revegetation to achieve erosion control. At least one author has suggested that no seeding should be done unless it has an 80% chance of success (293).

In the Low Arctic, studies of mud slumps initiated by engineering activities in the Mackenzie River delta region have indicated that natural revegetation can be relatively rapid. In such circumstances, where native species can establish quite rapidly, it is more sensible to allow natural revegetation to follow its own course as assisted revegetation would probably not speed up the process (215). In fact Younkin and Friesen (377) found that native species reinvasion was less successful as the amount of cover by seeded species increased. If the objective is to encourage a return of natural vegetation, there may be some circumstances where assisted revegetation will be a hindrance. However, in most situations it will probably be a matter of trying to decide on the *minimum* amounts of seed and fertilizer needed to encourage natural re-invasion of disturbed areas (378).

OBJECTIVES AND STRATEGIES FOR NORTHERN REVEGETATION

Revegetation practices in Canada have focussed overwhelmingly on the rapid establishment of a green cover on disturbed areas. This goal generally meets regulatory requirements and expectations for aesthetic improvement, and somethimes erosion control and provision of wildlife habitat as well. However, more and more revegetation specialists are stressing the encouragement of a stable, self-sustaining plant cover as the main objective during assisted revegetation (Index, sec. 2.5).

The wide range of ecological conditions encountered on mining wastes makes it unlikely that one set of regulations would ever be able to specify what constitutes an acceptable level of revegetation. As a result, much discretion must be left to each operator to develop a reclamation and revegetation program that will give the best results for each specific disturbed area.

Assisted revegetation can lead to development of soil-plant systems that will get better with time, or to systems that will get worse with time. If there has been a decision that assisted revegetation is a logical step for a given disturbed surface, the challenge is to do it in a way to encourage a soil-plant system that will improve with time. In many cases the best strategy will be to forget about "instant green" and to plan for a revegetated area that will be self-regulated. It may be less pretty at first but advantageous in the long run.

This overall strategy is expressed in a variety of ways in the revegetation literature but the repetitive theme is to strive for a maximum diversity of options. The literature contains many suggestions that more options are available with soil-plant systems that contain local, native species (or mixtures of native and agronomic species) than with soil-plant systems that use only seeded agronomic species.

There is not much evidence in the literature that revegetation goals can be defined to fit in with some set of predetermined alternative land-use plans. Where competing land uses are scarce, or where there are no regional land use plans in existence, one can do no better than guess what might be the best kind of vegetated surface to encourage. The best strategy would be to achieve rapid erosion control by whatever means is most effective; this may or may not involve revegetation. For the longer term, any land use plans that evolve will normally work with naturally occurring plant communities. Therefore, lacking land-use plans that call for a specific kind of managed vegetation cover, the soundest approach would be to undertake revegetation that encourages a return to conditions that one would generally expect to occur in the area. Exceptions to this approach would be in areas where aesthetic considerations were especially important. For example, intensive reclamation and specialized revegetation may be desired for recreational land uses around certain mine sites in Kluane National Park or on some of the old placer deposits near Dawson. In general, however, the best results in revegetation will be achieved from methods that work with nature to re-establish native vegetation as rapidly as possible.

UNDERSTANDING DISTURBED SURFACES AND THEIR PREPARATION FOR PLANT MATERIALS

Some of the existing literature conveys the impression that revegetation in the North is a special problem, distinct from revegetation problems in southern Canada, the United States or elsewhere. It is mainly only in the climatic limitations of botanical choices and in the relatively slower growth rates that the North is "different". Where physical principles are involved, such as the suggestion that "slopes on waste piles should be reduced to the biological angle of repose where revegetation is required" (135), the North is really no different than southern areas. This means that the northern revegetation worker can draw upon many southern principles, rules-of-thumb, or guidelines for the physical steps of revegetation.

Amongst the universal principles is the need to understand something about the disturbed surface before making any detailed plans for assisted revegetation. The minimum requirement is to recognize the basic kinds of mining waste materials as far as revegetation is concerned. This has been stressed in other reviews such as the U.S. Environmental Protection Agency review of vegetative stabilization of mineral waste heaps (90) and in the revegetation supplement of the *Pit Slope Manual* (270) where the focus was on a distinction between overburden, waste rock and tailings. In the present review, overburden, tailings and roads were suggested as appropriate categories. Roads were considered an integral part of mining operations, distinct from the other generally recognized categories of mine wastes. In any region, tailings must be recognized as a separate category of disturbed site as far as revegetation is concerned. In this review, overburden was taken as a broad term to include a fairly large variety of mining wastes, distinct from tailings and mining roads (as outlined on page *ii*).

If overburden, roads and tailings are accepted as the basic classes of disturbance that would influence a northern revegetation worker's plans for timing, species selection and fertilizer specifications, the next step is to focus on the specific factors that would influence assisted revegetation. Authors of the *Pit Slope Manual* concluded that climate, particle-size distribution, moisture retention, and mineralogy were the main factors that would tell an operator whether a particular site would be easy or difficult to revegetate (270). Unless or until future experience in the North suggests otherwise, these factors should be used as a guide to simplify the search for limiting factors on sites that are to be revegetated.

The literature dealing with factors limiting revegetation (Index, sec. 3), the importance of developing reclamation and revegetation plans as an integral part of the mining plan (Index, sec. 6.1), contouring and slope adjustment (Index, sec. 6.2), top soil addition (Index, sec. 6.3.1), use of sealants, matting, mulch or other organic matter additions (Index, Sec. 6.4 and 6.5) contains may general principles that can be applied to mining disturbances anywhere. These widely applicable principles do not need to be repeated here. The only requirement is that anyone who decides that assisted revegetation is to be done in a certain area must allow enough time for those in charge of operations to assess their specific area against such generally applicable principles. Case history accounts of revegetation (Index, sec. 4) indicate that the time and effort required for a better understanding of the surface to be revegetated is generally a better investment than rapid trial-and-error attempts to "get it green quickly".

In southern areas, tailings have been amongst the most difficult sites to revegetate and the same is expected to be true in the North. The special problems of tailings are emphasized in the next section. Other kinds of special problems will be presented by dry sites. For example, Hernandez (147) and others who have studied revegetation options for proposed northern pipelines have stressed that gravelly, dry sites are the hardest of all to revegetate. Of the sites tested in the pipeline revegetation studies, these difficult dry sites come closest of all to the conditions to be expected on many overburden or tailings areas.

Southern revegetation experience has often shown the importance of microhabitats for plant materials (110, 153, 380). It has also been noted that there is still a general lack of specialized reclamation equipment for creating the best surface topographies and microsites for plant establishment. Further experience will reveal the importance of these engineering steps for northern revegetation sites. In the North, where there are already regional climatic limitations to plant growth, there is reason to expect microtopography of surfaces to be even more critical than it is further south.

If the North presents special challenges for the engineering steps of reclamation, it may also present the opportunity for novel techniques. For example, many northern soils in their natural state have few, if any, distinct horizons because of mixing by freezing and thawing processes. Therefore, in cases where topsoil is being placed over a disturbed surface it may be less important to try to recreate the natural sequence of horizons as is done in southern reclamation, especially in agricultural areas. Interestingly, one novel technique under consideration in mountainous parts of the United States is the movement of frozen topsoil in winter when there is a greater chance of moving it without great mixing of organic and mineral horizons. The long periods of frozen soils in the North could provide opportunities for imaginative developments of techniques such as this in places where topsoil movement is part of a reclamation plan.

As a general rule, there is little point in undertaking revegetation steps before there is mechanical stabilization of the surface. Many reclamation workers view this as an engineering problem that must be solved before revegetation is undertaken, although other recent reviews have also stressed the importance of recent horticultural techniques including the use of surface binding materials which provide temporary terrain stability while vegetation is being established (91, 278). Any further development of new engineering techniques and revegetation must be based on the recognition that overburden and tailings sites vary so much that evaluation of individual site characteristics will generally be necessary.

THE SPECIAL PROBLEMS OF TAILINGS

Practically all mill tailings contain inorganic salts unsuitable for plant growth, lack organic materials and nutrients required by plants, and do not have physical features suitable for sustained plant growth (83). Despite these difficulties, some of the most productive revegetation research has been done on such difficult sites, including areas where metal toxicities are an added problem (2, 44).

Some of the oldest tailings in the Yukon are still unvegetated and some of the tailings areas that have been investigated indicate that further study is needed to develop suitable revegetation methods (13, 132). Studies of tailings in the Northwest Territories have also shown that unassisted revegetation will not occur in the short term (318, 320). There has not yet been much emphasis on acid problems associated with northern tailings areas, although it is known that this can be a particular problem in the North (13), as it is elsewhere in North America. Similarly, there has not yet been a northern emphasis on salinity problems, as there has been for much of the revegetation work in the Great Plains region. However, it is known that salinity is a problem for plant growth on some soils in the High Arctic (32), and similar responses can be expected on any saline tailings areas in the North.

Southern experiences with revegetation of tailings indicate that nearly always expensive and elaborate steps are required. These have involved additions of processed organic wastes (61) or other forms of organic matter (248), additions of various surface stabilizers (79, 81), burying of toxic materials (159), use of metal-tolerant species (2, 42, 43, 128), liming (240, 269), and a complex series of engineering and agricultural steps on tailings areas of the Precambrian Shield in Ontario and Quebec (221). There is no reason to expect revegetation of northern tailings to be any less difficult or less expensive.

THE CHOICE OF PLANT MATERIALS

One of the largest sections of the subject index in this volume is the one dealing with choice of species for revegetation (Index, sec. 5). Part of the reason for a large volume of literature on this topic is the continuing debate on relative merits of agronomic species versus native species. For areas not being revegetated to an agricultural land use, there is an increasing consensus in favour of native species, despite the unsolved problems of seed supply for these species. For revegetation of difficult sites, such as those at high elevations, the approach currently in favour is one involving a compromise between agronomic and native species. The approach described by Milligan and Berdusco for Kaiser Resources Ltd. (252) is an example. Although this company continues to use agronomic species of legumes and grasses, they recognize that this approach may not be the most suitable in the long run, and they predict that use of native species will increase in the future, especially at higher elevations. In the North, too, revegetation studies related to proposed pipelines have shifted from an early emphasis on a dense cover of agronomic species to revegetation methods that encourage re-invasion of native species (372, 373). The interested reader can find a discussion of the pros and cons of native versus introduced species in the review by Johnson and Van Cleve (163).

The factors to consider during choice of species are too numerous to review here, but there are several general principles for consideration in the North. Because there has been considerable success with revegetation of test pipeline berms, there will be a temptation to apply the resulting revegetation specifications (373) to a wide variety of disturbed sites in the North. It must be stressed, however, that most of the recommended grasses for pipeline right-of-way revegetation are meadow species that would do well on the moist to wet habitats expected along the proposed pipeline route (378). For drier sites, such as would be expected on most overburden and tailings, published pipeline revegetation specifications suggest very few candidate species except for creeping red fescue and Kentucky blue grass (377).

Southern revegetation strategies that involve direct planting of tree species on disturbed sites (234, 299) likely hold little promise for the Yukon and Northwest Territories, except perhaps for poplars, alders and willows. A considerable amount of literature suggests that it would be more productive to search for local candidate species from sources such as: the oldest mining disturbances in an area (85, 276); plants adapted to naturally occurring disturbances or young surfaces (Index, sec. 10.2); non-leguminous nitrogen-fixing species, many of which are pioneers on naturally disturbed areas (Index, sec. 5.4); and woody plant materials in general (85, 104, 384). Several recent publications have stressed the need for more attention to rooting characteristics when candidate species are being identified (17, 277, 278).

In summary, it is important to conduct field trials of candidate species before there is a commitment to major seeding or planting programs. In general, the greatest chances of success will occur where revegetation programs include multiple methods such as seeding, cuttings and physical aids to erosion control. The roles of nitrogen-fixing species, mycorrhizae, and micro-organisms in general are no less important in northern areas than they are further south (77, 244, 245).

WHERE TO GET SEEDS AND PLANTING STOCK

Surprisingly few revegetation reports tell a user specifically where seeds are available commercially. Seed distributors are identified for each licenced grass and legume variety in Canada Department of Agriculture Publication No. 1405, by Elliott and Bolton (101). Canadian revegetation specialists can obtain comprehensive listings of seed dealers by contacting organizations such as the Canadian Seed Trade Association, Pacific Seedsmen's Association, or the Western Seed Trade Association. An indispensable booklet, giving names, addresses and phone numbers of Canadian seed distributors, is the 1977 Membership Directory of the Canadian Seed Trade Association (L'Association Canadiene du Commerce des Semences), available from Suite 210, 100 Dixie Plaza, Mississauga, Ontario, L5E 1V4.

There are no comparable directories for sources of seedlings and other kinds of vegetative materials for planting. Unlike the well-developed seed trade, materials for vegetative propagation are more dependent on local collection areas or the ingenuity of the revegetation officer.

DECIDING WHETHER TO FERTILIZE

Fertilizer specifications are such a regular feature of the revegetation literature (Index, sec. 6.11.2) that it is easy to overlook the fundamental question of whether or not to fertilize (Index, sec. 6.11.1).

Some authors have conducted revegetation trials without fertilization on the reasoning that species that need constant fertilization have little use in revegetation work (377). It is also important to note the inability of unadapted species to use soil nutrients in cold soils (236), which indicates that poorly adapted species cannot be stimulated by fertilization.

In general, fertilization will enhance non-native species to the disadvantage of native ones. Although limited fertilization may assist the establishment of pioneer species, continued fertilization will tend to inhibit the development of self-sustaining nutrient cycles (244). In areas of low erodibility where a heavy plant cover does not need to be maintained the use of heavy fertilizer applications is questionable (11, 378).

SUMMARY AND RECOMMENDATIONS

1. In spite of the abundant literature on revegetation, there are still no guaranteed methods for revegetation of difficult sites (90). Even the most comprehensive revegetation studies in northern Canada, involving six years of work, have resulted in revegetation specifications that are considered by the authors (373) as "preliminary". In Alaska, too, a review of revegetation research from the Arctic Coastal Plain stressed that many conclusions are tentative but that much new information will be available in the next few years (382). In Alberta, reasearchers involved with widespread field trials of candidate species stressed that preliminary recommendations could be made within two years but complete recommendations may require up to 10 years of study (345).

2. Reclamation programs do not necessarily need to automatically include revegetation steps. Revegetation, by itself, is not a guaranteed solution for control of alluvial or thermal erosion. Slope stability must be achieved by appropriate methods of materials handling in the engineering phases of mining. There is a need for more precise criteria to aid the decision whether assisted revegetation should be attempted on various kinds of disturbed areas in the Yukon and Northwest Territories.

3. The rapid achievement of a dense cover of agronomic grasses and legumes remains as an objective in many areas of southern Canada, especially where there are agricultural land uses of reclaimed land. However, this approach is being increasingly questioned for difficult sites or high elevation sites in southern Canada. Its use in the North is even more questionable. An alternative strategy that seems better suited to

conditions in the Yukon and Northwest Territories is to determine the *minimum* amounts of seed and fertilizer needed to encourage natural reinvasion of disturbed areas.

4. Some of the best information available today is for those plant species that have been subjected to basic ecological studies, such as the grasses, *Arctagrostis* and *Calamagrostis* (369), cottongrass (358), or *Dryas* (219). Other high priority species for similar studies would be *Festuca brachyphylla* and *Poa lanata*. Detailed information on the ecology and physiology of northern willows and alders may also be useful to develop more ways to use unrooted cuttings in northern revegetation programs.

5. Whenever there is a commitment to undertake assisted revegetation there should also be a commitment to provide long-term maintenance, management, and follow-up assessments of the revegetated areas (Index, sec. 6.12).

6. The shortage of seeds and other materials for planting will not be remedied until there is establishment of plant materials centres in the North, such as that at Palmer, Alaska (45), or development of co-operative nurseries for use by operators in a local area (86).

7. If a system of ecological reserves is established in the Yukon and Northwest Territories, the system should include some examples of lands disturbed by mining. Long-term studies of the ecology and evolution of naturally invading plant species should be centred on such outdoor laboratories. The highest priority study needs are outlined in other reviews of revegetation (167) and by many other individual revegetation workers (Index, sec. 12).

8. Although much of the revegetation literature is recycled information, this is an active field of study at present in Canada. To indicate how quickly a review volume such as this one becomes outdated, new sources of information that became available in a 2-month period after this review's March 1977 cut-off date included:

   Abbott, D. 1976. Bibliography of mine waste revegetation in Canada. Report No. M/77/133, Research and Productivity Council, Fredericton, New Brunswick.

   Andrews, M. 1977. Selected bibliography of disturbance and restoration of soils and vegetation in permafrost regions of the U.S.S.R. (1970-1976). Special Report 77-7. U.S. Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. 116 p.

Foothills Pipe Lines (Yukon) Ltd. 1976. Revegetation. IN: Environmental Statement, Vol. 5B-1. Application before the National Energy Board and to the Department of Indian and Northern Affairs. p. 412-420.

Takyi, S.K., M.H. Rowell, W.B. McGill and M. Nyborg. 1977. Reclamation and vegetation of surface mined areas in the Athabasca tar sands. Environmental Research Monograph 1977-1, Syncrude Canada Ltd. 170 p.

Vaartnou and Sons Enterprises Ltd. 1977. Native seed multiplication. A progress report on work accomplished in multiplying seed stock of native ecotypes useful for northern revegetation. Prepared for Foothills Pipe Lines Ltd. 20 p.

Vaartnou and Sons Enterprises Ltd. 1977. Native revegetation research, Progress Report 1976. Prepared for Foothills Pipe Lines Ltd., Alberta Gas Trunk Line Ltd., and Westcoast Transmission Ltd. 58 p.

Conference proceedings and periodic reviews are therefore important steps to inform revegetation workers of new developments. Plans by the Canadian Land Reclamation Association to publish an international journal, entitled *Reclamation Review*, through Pergamon Press, will also help to fulfill this need.

ANNOTATED REFERENCES

1. AIELLO, J.

2. 1973

3. Open pit coal mining at Cardinal River Coals.

4. In: Proceedings of the 25th Canadian Conference on Coal. Published by Energy Development Sector, Department of Energy, Mines and Resources, Ottawa. p. 79-84

5. Original

6. a. Alberta; Rocky Mountains

   b. Alpine; Overburden

7. Cardinal River Coals Ltd. operates an open-pit coal mine approximately 200 miles west of Edmonton in the subalpine zone on the eastern slope of the Rocky Mountains. Mine development and prestripping were started in 1969. The Canadian Forestry Service, in co-operation with Cardinal River Coals, initiated several test plots on old dump areas in the vicinity of the Luscar mine in 1969 and 1970. Fifty-eight acres of dump area were hydroseeded in 1971 and a seeding program on 118 acres in 1972 included the following trial species:

blackberried elder
wolf willow
snowberry
wild rose
white birch
Russian olive
sage
saskatoon
honeysuckle
sandcherry
Siberian crabapple
Siberian pear
common lilac
fourwing saltbush
small burnet
sheep fescue
alta fall fescue
Canada bluegrass
upland bluegrass
Fairway crested wheatgrass
pubescent wheatgrass
timothy
Chemung crownvetch
cicer milkvetch
sweet clover
alfalfa
sainfoin
lodgepole pine
yellow clematis

Survival results of these trial species were not recorded in this paper.

1. ANTONOVICS, J., A.D. BRADSHAW and R.G. TURNER

2. 1971

3. Heavy metal tolerance in plants.

4. In: J.B. Cragg (Editor), Advances in ecological research. Volume 7. Academic Press, London. p. 2-85

5. Original

6. a. World-wide

   b. Yukon and Northwest Territories; Tailings

7. This review of the world-wide literature on heavy metal tolerance in plants provides lists of vascular plants, mosses, liverworts, lichens, algae and fungi reported to be present in contaminated soils. Factors determining plant distribution on contaminated soils, the evolution and genetics of heavy metal tolerance and mechanisms of metal tolerance are also reviewed in detail. A concluding section on practical applications of knowledge about metal-tolerant organisms discusses biogeochemical prospecting, ore extraction, and the establishment of vegetation on toxic waste materials. Only the latter subject is annotated below.

Tailings contain not only the remains of the metal that has been extracted but also quantities of the other metals that were present in the ore and not extracted. These metals are released slowly as soluble compounds as the ore weathers, and may continue to be released for centuries. As a result the waste heaps have very little plant growth upon them, owing to the combined effects of toxicity, lack of nutrients and physical conditions.

The most obvious technique that will be effective is to cover the toxic material with a layer of normal soil and establish a herbage cover or trees in the normal manner. This is, however, exceedingly expensive, usually at least six times the normal for non-toxic areas.

An alternative approach is to take advantage of the natural evolutionary processes that have already occurred and employ species and populations which are already tolerant to the toxicity present, together with fertilizer to ameliorate nutrient lack. The authors stressed that the technique of using metal-tolerant populations has not been explored in a wide enough variety of sites. But initial results are promising and fit in with expectations. There is such a wide variety of species in all parts of the world in which tolerance is known or can be presumed to occur, that it seems a method capable of widespread use. Many of the species are vegetatively vigorous and perennial, and some are leguminous

Continued ...

Antonovics, J., A.D. Bradshaw and R.G. Turner. 1971. Continued

and therefore will perhaps be self-sufficient for nitrogen unless N fixation is precluded by toxic soils. The method should be investigated further.

Specialized habitats such as metal-contaminated areas are extremely valuable to evolutionary and ecological studies. Their value stems essentially from their simplicity. The sequence and pattern of genetic change responsible for colonization of metal-contaminated areas is a unique record of natural selection in action. The work described in this review article indicates that certain problems of ecology can often be better analysed in environments that are highly specialized or even man-made, than in natural, more complex habitats.

1. ARKAY, K.E.

2. 1975

3. Exploration and abandonment environmental aspects.

4. In: Seminar notes, Technology transfer seminar on mining effluent regulations/guidelines and effluent treatment technology as applied to the base metal, iron ore and uranium mining and milling industry, Environment Protection Service, Environment Canada. Draft Text. 36 p

5. Original

6. a. Canada

   b. Yukon and Northwest Territories; Tailings

7. Environmental problems resulting from abandonment of tailings and waste rock areas, open pits and underground workings of mining can occur long after termination of mining activity. The most common environmental problems relate to water pollution. In addition, problems from air pollution from wind erosion and transport of sediment from tailings are significant as is aesthetic degradation.

To prevent long-term environmental problems, it is imperative that forethought and careful planning are invoked for the disposal and treatment of mining wastes. One objective is to ensure structural stability of wastes, for which the most satisfactory method is to seal waste by revegetation. Revegetation can increase the long-term stability of waste deposits by increasing evapotranspiration rates and thus reducing the quantity of water entering deeper levels of the deposit. Technical problems of revegetation vary with several factors such as local climate, topography of the waste dump, grain size and distribution, availability of plant nutrients, the presence of phytotoxicants, and the ability to use heavy equipment.

It is estimated that low-sulfide tailings in Canada can be revegetated at costs of between $125 and $500/acre which includes grading and surface preparation, seeding, fertilizer and temporary chemical binders. It is also assumed for these figures that wastes are relatively level, no major phytotoxicants are present and the climate is temperate and non-arid. Revegetation of extremely coarse waste rock can be much more expensive than the figure suggested above if some soil cover is required for plant establishment.

Continued ...

Arkay, K.E. 1975. Continued

Not all non-reactive wastes are amenable to revegetation. A solid revegetation cover is impossible to establish in the High Arctic, in arid areas or on certain wastes with unsuitable physical or chemical characteristics. Physical sealants (soil, bark fines, smelter slag) or chemical sealants (latex emulsions) can be used independently or in conjunction with vegetation. Used alone they provide only temporary cover; erosion will occur and repeated applications are required.

The author suggests that post-abandoment pollution problems should be evaluated and incorporated in the planning stage of a mine for the best long-term preventative measures. To ensure rehabilitation of abandoned mining operations a pre-operational bond and/or royalty could be required and calculated on the basis of cost for revegetation of non-reactive wastes and adjusted to amounts on the basis of sulfide percentage in the waste.

The author listed several specific problems needing resolution: determination of methods to establish self-sustaining vegetation cover on sulfide tailings; assessment of the usefulness of such vegetation covers in reducing water contamination by reactive sulfides; and development of alternate methods of sealing surfaces of chemically reactive pits and waste to prevent acid generation.

1. BABB, M.F.
2. 1959
3. Propagation of woody plants by seed.
4. University of Alaska, Alaska Agricultural Experiment Station, Palmer, Alaska. Bulletin 26. 12 p
5. Original
6. a. Alaska; Central Alaska Taiga, Southern Alaska Taiga

   b. Yukon and Northwest Territories; Overburden, Roads

7. Several methods of propagation of woody plants by seed are described, including direct seeding in fall and stratification of seed in preparation for sowing. Stratification requires alternating layers of moistened sand, peat or sphagnum moss with the seeds and placing them in controlled conditions suitable for germination. The time of stratification is adjusted to the planting date, so that seed planned for sowing on May 1 and requiring 75 days stratification is placed under stratification on February 15. Adjustment is made for local planting conditions and species requirements, with special attention given to maintain proper moisture in the chosen container. Fall sowing is recommended for the seed of most woody plants. When this is possible, the overwintering of the seed in cold, moist soils provides the most nearly normal conditions for breaking the dormancy of the seed embryo and stimulating germination.

Two temperatures are indicated for stratification: 41° F for low temperature range; and 77° F for a high temperature range. Pre-planting treatment is shortened by increasing the stratification temperature. Some species need two stratification periods and some are quite variabile in their requirements. Certain genera require pre-treatment before stratification to permeate thick or hard seed coats. Most common treatments are hot water (180° to 200° F), soaking in concentrated sulfuric acid (a commerical grade of 1.84 specific gravity) or scarifying with abrasives either mechanically or by hand. Commercial seed of woody plants is usually pre-processed by a seedsman and requires storage in a cool (between 33° and 50° F) and dry place until needed.

Although fall sowing is recommended for the seed of most woody species there are problems associated with fall planting. These are: (1) seeds are food for mice and other animals; (2) there is a danger of alternating freezing and thawing; (3) there is a danger of excessive drying in winter; and (4) there is the problem of weed control in spring. To avoid these problems and to ensure breaking of seed dormancy, the seed is usually stored, then later removed for stratification or other pretreatment before sowing in the spring.

Continued ...

Babb, M.F. 1959. Continued

In vegetative propagation, a portion of the parent plant is induced to form roots or it can be united to a compatible plant with an established root system. In the first instance, cuttings, divisions and layers may be used on such natural plant parts as suckers, runners and rhizomes. Budding or grafting to a compatible species takes advantage of the root system of another plant to secure greater winterhardiness, insect resistance, tolerance to adverse soil conditions or selection for other superior characteristics. Many woody plants seldom reproduce perfectly true to type from seed and for this reason, and for the purpose of increasing stocks, selected strains are often propagated by vegetative means.

A table at the end of the article lists general methods of propagation for specific trees and shrubs. Information for genera that might be used at northern mining sites is as follows:

1. *Abies* - Fall sow, or stratify 60 to 90 days at 41° F and sow in spring. Variable. Also by cuttings.

2. *Alnus* - Spring sow non-dormant seed. Fall sow dormant seed, or stratify 60 to 90 days at 41° F, then sow in spring. Variable. Also by 1-foot hardwood cuttings.

3. *Amelanchier* - Fall sow, or stratify 120 to 180 days at 41° F and sow in spring. Variable. Also by grafting, cuttings, layering and division.

4. *Arctostaphylos* - Fall sow some species after soaking in H_2SO_4 three to six hours. Stratify others 60 days at 77° F plus 60 days at 41° F. Variable. Also by cuttings.

5. *Betula* - Spring sow spring ripening seed. Fall sow fall ripening seed, or stratify 60 to 75 days at 41° F. Also by layering, cuttings, budding and grafting.

6. *Elaeagnus* - Fall sow, or stratify 90 days at 41° F and spring sow. Also by hardwood cuttings, root cuttings, layering and grafting.

7. *Empetrum* - Fall sow, or by hardwood cuttings in August.

8. *Juniperus* - Stratify 90 to 120 days at 77° F followed by 90 to 120 days at 41° F. Highly variable. Most species also from cuttings; some from layering.

9. *Kalmia* - Spring sow in greenhouse. Also by layering.

10. *Larix* - Fall sow, or stratify 30 to 60 days at 41° F and spring sow.

11. *Ledum* - Spring sow in greenhouse. Also by layering and division.

Continued ...

Babb, M.F. 1959. Continued

12. *Picea* - Spring sow non-dormant seed. Fall sow seed of species bearing dormant seed, or stratify it for 30 to 60 days at 41° F. Highly variable. Also by cuttings and grafting.

13. *Pinus* - Spring sow non-dormant seed. Fall sow dormant seed or stratify 30 to 90 days at 41° F. Highly variable. Also rarely by grafting and cuttings.

14. *Populus* - Sow seed as soon as ripe. Also by stem (except aspens) and root cuttings.

15. *Potentilla* - Sow seeds as soon as ripe. Also by division.

16. *Prunus* - Fall sow or stratify. Some species 90 to 150 days at 41° F, others 60 to 90 days at 77° F, plus 60 to 90 days at 41° F. Highly variable. Also by budding, grafting, suckers and root cuttings.

17. *Ribes* - Sow as soon as ripe, or fall sow. For spring sowing, stratify 90 to 120 days. Also by suckers and hardwood cuttings.

18. *Rosa* - Treat with H_2SO_4 for 1 to 2 hours plus stratification for 90 to 120 days at 41° F. Also by hardwood and root cuttings, budding, suckers, layering, and grafting.

19. *Rubus* - Sow as soon as ripe or treat with H_2SO_4 for two hours followed by stratification for 90 days at 68° to 86° F plus 90 days at 41° F. Also by layering, suckers, stem and root cuttings.

20. *Salix* - Sow seeds as soon as collected. Keep moist. Hardwood cuttings best.

21. *Shepherdia* - Fall sow, or stratify 60 to 90 days at 41° F. Also by suckers.

22. *Sorbus* - Fall sow, or stratify 90 days at 77° F plus 90 days at 41° F. Some stratify 90 days at 33° F. Highly variable. Full germination takes two to three years.

23. *Symphoricarpos* - Spring sow and mulch for germination the following spring, or treat with H_2SO_4 for 30 to 75 minutes, followed by stratification at 77° F for 30 days plus 180 days at 50° F. Highly variable. Also by softwood and hardwood cuttings and division.

24. *Vaccinium* - Fall sow, or stratify 150 days at 41° F. Divisions and cuttings preferred.

26. *Viburnum* - Sow in spring or early summer for good germination the following spring, or stratify 120 days at 77° F plus 60 days at 41° F and spring sow for germination the following spring. Also by greenwood or hardwood cuttings and layering.

1. BABB, T.A.
2. 1972
3. High Arctic disturbance studies.
4. In: L.C. Bliss and R.W. Wein, Editors, Botanical studies of natural and man-modified habitats in the eastern Mackenzie Delta region and the Arctic Islands, Arctic Land Use Research program, Indian and Northern Affairs, ALUR 71-72-14, p 230-281
5. Original
6. a. Queen Elizabeth Islands; Canadian Tundra

   b. Arctic Islands; Overburden, Roads

7. The environmental effects of man's activities were assessed at various locations in several Canadian Arctic Islands - Bathurst, Cornwall, Devon, Ellesmere, Ellef Ringnes, King Christian, Mackenzie King and Melville.

On the xeric sites which predominate in the High Arctic (areas of polar desert, "silt crust" terrain, beach ridges, and sandy areas), environmental harshness is more limiting than biotic factors and succession is a slow, one-step process of re-invasion of the species formerly present. Recovery can take 5 to 100 years depending on: (1) growth rates of the species present and the time required for initial establishment; and (2) whether local dominant species are quickly established and fast-growing (perennial grasses) or slowly established, long lived and slow-growing species (*Salix arctica, Dryas integrifolia* and lichens). Species re-invading on dry sites are efficient seed or bulbil producers such as *Papaver radicatum, Draba* spp., *Parrya* spp., *Saxifraga* spp., *Oxyria digyna, Polygonum viviparum* and several grasses.

Succession on mesic and hydric sites is difficult to assess and the prevalent mechanism is slow lateral invasion by rhizomes from root stocks of sedges and grasses in adjacent undisturbed areas. Natural re-seeding is not common. In some areas, mosses have a more important role in initial re-invasion than vascular plants. The temperature gradient of the active layer alone may account for a moisture gradient from dry at the surface to wet at a depth of 10 cm or more in most fine-grained polar desert soils. The strong moisture gradient has primarily been related to poor drainage caused by an impermeable permafrost table. During summer months moisture in fine-grained soils near the base of the active layer promotes soil instability, especially if compaction or removal of surface layers increases the thaw depth. Changes in soil moisture may be enough to slow natural revegetation.

1. BABB, T.A. and L.C. BLISS

2. 1974

3. Effects of physical disturbance on arctic vegetation in the Queen Elizabeth Islands.

4. Journal of Applied Ecology 11:549-562

5. Original

6. a. Queen Elizabeth Islands; Canadian Tundra

   b. Arctic Islands; Overburden, Roads

7. This article describes manipulation experiments in the Truelove Lowland on Devon Island and past disturbances at several industrial sites elsewhere in the Canadian Arctic Archipelago. The objectives were to determine the effects of physical disturbance and to assess the capacities of natural plant communities for recovery. Manipulation experiments were conducted in mesic sedge and moss meadow habitats which, because of their concentrated biomass and susceptibility to physical disturbance, are the most likely sites of biological damage. Manipulations included controlled vehicle passage, removal of vegetation to simulate blading (scraping of the surface by bulldozer) and periodic clipping of above-ground plant parts leaving peat and rhizomes intact (simulated grazing). Fertilization trials and controlled oil spills were additionally conducted in both xeric and mesic habitats.

Studies elsewhere have shown that plant cover does not act simply as an insulative barrier to the flow of sensible heat. For example, removal of vegetation and peat from low arctic tundra surfaces increased the thaw depth by 50 to 100%, but replacement of the same material as mulch decreased this by only 40%. Studies described in this report have shown that thaw and associated problems on disturbed sites, even where vegetation is relatively dense, are much less important in more northerly arctic regions than they are in the Low Arctic. In the High Arctic, even a relatively densely vegetated surface has a canopy and moss layer too sparse to strongly moderate the amount of energy actually reaching the soil; thus removal of vegetation has little effect on increased heat flux and subsequent thaw. By these observations the authors do not necessarily imply that revegetation is unimportant in the High Arctic. They point out that renewal of vegetation where damage has occurred is desirable from an aesthetic and ecological standpoint. The destruction of vegetation in limited areas of high plant cover is unsightly at best, and at worst, may seriously deplete available forage for native herbivores.

Continued ...

Babb, T.A. and L.C. Bliss. 1974. Continued

The most rapid re-invaders on entirely denuded sites are the most efficient seed or bulbil producers (*Papaver radicatum, Draba* spp., *Saxifraga* spp., several grasses, *Oxyria digyna, Polygonum viviparum* and others). Slow growing, woody perennials (*Salix arctica, Dryas integrifolia,* and *Saxifraga oppositifolia*) do not become conspicuous until much later. Mosses normally appear rapidly in favourable micro-sites, and, where vascular plants afford additional protection from wind and desiccation, they multiply concurrently with these larger species. Lichens grow extremely slowly, and no indications of successful re-invasion were found.

Under special circumstances certain species are favoured by disturbances. Such species have been called hemerophiles. Notable examples of such plants from the High Arctic which could be useful in revegetation of sites where soil stabilization or renewal of an organic layer are desirable include: *Arctagrostis latifolia, Puccinellia angustata, Alopecurus alpinus, Poa alpigena* var. *colpodea,* and *Cerastium alpinum.*

The severe environment of the High Arctic limits rates of natural revegetation. While on most sites plant cover is too sparse to warrant attempts at rehabilitation, in some heavily vegetated areas efforts to stimulate recovery may prove necessary. Reseeding would probably be of limited success because of unfavourable summer temperatures for non-native species and the low availability of native seed sources. Fertilization shows some promise and could be useful where the main concern is to re-establish cover regardless of species composition. Because community changes resulting from fertilization may disfavour important dominants (e.g. *Dryas integrifolia*), the practice would not be useful in all cases.

1. BAYLES, F.D. and M.A. DUDLEY
2. 1976
3. Stable seed sheets - an alternative approach to revegetation.
4. In: Proceedings of the Inaugural Meeting Canadian Land Reclamation Association, Crop Science Department, Ontario Agricultural College, University of Guelph, Guelph, Ontario, p 1-17
5. Original
6. a. New Jersey; Eastern Forest

   b. Yukon and Northwest Territories; Overburden, Roads, Tailings

7. A method of developing water-soluble seed-containing polymer sheets is described. These sheets are stable, easily stored and easily applied from roll and sheet form. They have an adjustable formulation for use in a variety of climatic areas with a wide range of precipitation conditions. They are designed to give a controlled speed of resolubilization and to provide sufficient soil cohesion until a root matrix is formed. The sheets contain seed, fertilizer, herbicides, and other additives required for quick development of an erosion-controlling groundcover. An advantage is that they allow uniform seed distribution and optimum concentration of seed to be applied in a simple manner which is readily repeatable. The sheet is laid on the ground where it provides soil consolidation and a microenvironment conducive to germination and growth.

Experiments were conducted in New Jersey with seven varieties of seed frequently used in revegetation (alfalfa, dogtooth, Baron bluegrass, Alaska clover, sweet clover, crownvetch, birdsfoot trefoil) and a seed mix consisting of bluegrass, creeping red fescue, ryegrass and colonial bentgrass. The objective was to determine the effects of encapsulation on germination and growth. In general, dicotyledons germinated more quickly than monocotyledons, but showed poor root formation. Monocotyledons had slow germination rates but excellent root growth. Little effect was observed on germination or growth by encapsulation of seed in a seed sheet. Outdoor experimental sheets germinated in nine days with 75% germination after 18 days.

Comparative cost studies indicate that seed-sheet production, ground preparation and laying of the sheets are competitive with other techniques used in mine tailings revegetation. The product is produced by Canada Wire and Cable which is seeking sales and licence authorization for this technology.

1. BAYNE, D.A.

2. 1975

3. Revegetation of tailings areas at vacated mines near Carcross, Yukon Territory.

4. Report submitted to K.W. Gullen, Water Resources Section, Department of Indian and Northern Affairs, Whitehorse, Yukon Territory. 15 p

5. Original

6. a. Yukon; Southern Yukon

   b. Southern Yukon; Tailings

7. This work examined the feasibility of revegetating two tailings ponds, one at Arctic Mine (60 08 N, 134 43 W, elevation 3400 feet) and one at Venus Mine (60 03 N, 134 35 W, elevation 2200 feet), both located near Carcross and both abandoned for some years.

No growth was achieved on sample plots at Arctic Mine due to low pH that ranged from 2.0 to 2.3. The methods used in this study were not effective on such extremely acid substrate with high sulphuric acid content. The low pH increased the solubility of aluminum and manganese both of which occurred in toxic levels. Manganese is an essential element to plants but in concentrations exceeding 5 ppm toxicity results. Particle size analysis indicated that the fines in these tailings had the tendency to flocculate which indicated that the substrate is composed of many undissociated clay colloids.

Liming is a possible solution to the low pH of Arctic Mine tailings but massive amounts would be required. Partial liming is a better solution in conjunction with carefully chosen plant species tolerant of relatively acid conditions. Raising the pH to 5.0 would permit acid tolerant species to take hold.

Most plants tested at Venus Mine germinated but exhibited varying degrees of growth at the end of the first growing season. Slender wheatgrass and creeping red fescue grew the best of eleven species tried and application of 1000 lb/acre 10-30-10 fertilizer produced the best results.

Slender wheatgrass thrives under conditions of good moisture and tolerates saline soils. Creeping red fescue is native to northern Alberta and is adapted to northern and high altitude environments.

The Venus Mine could be economically revegetated using a mix of these two species in combination with smooth brome grass, climax timothy and inoculated trefoil. Such a mix is composed of perennial species with

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Bayne, D.A. 1975. Continued

both rhizomatous and fibrous root systems; the leguminous root nodules would ensure the cycling of nitrogen and the grasses could be grazed. The Venus Mine tailings are neutral (7.2 and 7.0 pH in two soil samples) so that the main problems inhibiting growth are low nitrogen, phosphorus and potassium and moderate to high salinity (sulphate ion concentration).

Further applications of fertilizer may be required to maintain nutrient levels, especially since the organic matter produced by decaying plants requires time to decompose and become available for use. First year plants are unlikely to produce seed. Long term monitoring is required to ensure that the plant community can regenerate itself and further seeding may be necessary.

The author recommended a literature review for comparison with similar studies.

1. BELL, K.L.

2. 1975

3. Aspects of seed production and germination in some high arctic plants.

4. In: Bliss, L.C., Editor, Plant and surface responses to environmental conditions in the western High Arctic, Department of Indian and Northern Affairs, ALUR 74-75-73, p. 62-72

5. Original

6. a. Queen Elizabeth Islands; Canadian Tundra

   b. Arctic Islands; Overburden, Roads

7. Although seed production, germination and seedling survival are generally poor in the more extreme tundra environments, there is still an incentive to understand seed reproduction for high arctic species because, if it is successful, sowing seeds is a relatively simple method of revegetating disturbed sites. In this report, the author describes experiments that were undertaken to determine the possibility of seeding for revegetating in a polar semi-desert. Seed production, germination in field conditions and seedling survival were investigated, and controlled environment studies were conducted to ascertain optimum conditions for germination.

Within a study area on King Christian Island, many species failed to set seed or had low rates of seed set in 1973. At the time of fall freezing in 1973, 13 of 27 species flowered, but failed to produce mature seed and disperse them. Infloresences of plants of 16 species that developed but failed to set seed in 1973, were examined in July, 1974. All were brittle and contained shrivelled seed. None yielded viable seed except *Potentilla hyparctica* and *Cerastium alpinum.* In 1974, many species progressed no further than anthesis before the brief summer ended. Only one species, *Saxifraga cernua,* successfully produced propagules.

Germination was poor in a variety of habitats. Of 3425 seed sown in late June, only 142 germinated and of these 75 survived until 20 August. There were two peaks of germination, both after snowmelt. Sixty-five seeds germinated within one week of sowing in late June. Between 10 July and 10 August, only 18 seeds germinated. During the period of 10 to 15 August, snow fell and melted several times. Fifty-eight seeds germinated during and after this precipitation.

Germination appeared closely-linked to surface moisture. In the lichen barrens, no seed germinated. Germination was very low in the untilled disturbed site and the barren mud cracks, 0.3 and 1.3% respectively.

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Bell, K.L. 1975. Continued

Moss surfaces in the meadows held water around seeds, and overall germination was 4.2 and 9.2% in the dry and moist meadows respectively. Seeds falling deep into crevices of the tilled site also germinated relatively well, with overall germination of 4%.

Although natural seed reproduction is low, seeding may be used for revegetation. Low rates of seed production in the northwestern portion of the Canadian Archipelago make seed collection there difficult. Seed could be collected more readily near Resolute in the sewage disposal area or perhaps in the northeastern islands. Germination prior to sowing may help establishment of *Phippsia algida* by circumventing the lag before germination. Seeds are probably best germinated if stored in water at 1 to 2° for four weeks before being placed in shallow water at 12°. Although seedling mortality will probably be high, it can be reduced by roughening soil surfaces. Under these conditions, reseeding denuded areas may have moderate success.

1. BELL, K.L.

2. 1975

3. Root adaptations to a polar semi-desert

4. In: Bliss, L.C., Editor, Plant and surface responses to environmental conditions in the western High Arctic, Department of Indian and Northern Affairs, ALUR 74-75-73, p. 21-61

5. Original

6. a. Queen Elizabeth Islands; Canadian Tundra

   b. Arctic Islands; Overburden, Roads

7. In the Low Arctic, below-ground plant parts make up the bulk of vascular plant biomass, but in polar semi-deserts 50 to 80% of the plant biomass is above-ground. The reasons for this apparent reduction in root growth in polar desert areas are not known and this study was designed to examine this question. The author suggested that an understanding of conditions limiting root growth may be useful in developing effective revegetation techniques. The extreme reduction in root growth in polar semi-deserts suggests that plants find the edaphic environment even more hostile than that above ground. Thus, for either transplanting or reseeding to be effective, choice of species with maximum root growth capability in very cold soils may be beneficial. This study examined root growth in a polar semi-desert on King Christian Island, N.W.T. One of the goals was to identify species suitable for revegetation and to determine what methods of revegetation offer the most promise of success. Position and shape of the roots of native species were examined; root growth rates in various environments were measured; the effects of soil temperature on root growth were studied; and the role of roots in the overall plant economy was assessed.

Root morphology was examined in 30 of 32 species found on King Christian Island. Mature plants of 12 species had taproots but in all cases they were short, usually less than 5 cm, with maxima of 18 cm in *Draba bellii*, 28 cm in *Potentilla hyparctica*, and 33 cm in *Papaver radicatum*. All species except one (*Cochlearia officinalis*) had numerous adventitious roots. Roots were almost entirely confined to the upper half of the active layer. Maximum thawing depths were *ca.* 39 to 62 cm in both 1973 and 1974, with the deeper active layers in dry sites. In the drier sites from the lichen barrens to the dry meadow, maximum rooting depth was usually about 25 cm and most roots of larger species reached about 15 cm depth. On ridgetops, roots penetrated the soil freely, but concentrated under small surface depressions. In lemming gardens, most roots grew straight down through a moss layer to about 20 cm depth, a few to 40 cm in loose, moist soil.

Continued ...

Bell, K.L. 1975. Continued

Roots of all species, except *Alopecurus alpinus* and *Cochlearia officinalis*, appeared unimportant for storage. Over-winter storage tissue was found in wintergreen leaves in all species and in expanded rhizomes of *Alopecurus* and *Luzula confusa*.

There appeared to be a strong selection for adventitious root systems on King Christian Island. Several factors may favor these systems. Breakage from natural soil movements could have less impact on an adventitious root system than on a branched taproot system. Adventitious roots near the surface could form a by-pass of more deeply-buried roots which remain frozen until late in melt. High resistance to water movement in cold plant tissues could also be partially alleviated by adventitious roots arising at intervals along prostrate stems. Finally, for the species reproducing asexually, adventitious roots are important for establishment of new plants. At least ten species on King Christian appear to rely heavily on asexual reproduction, and adventitious root systems are well developed in all these species.

Although mass wasting processes are very rapid on King Christian Island, vascular plants appear to play some role in soil stabilization. The most notable instance is that of riverbank stabilization by *Phippsia algida*. *Alopecurus alpinus* also appears to impede rapid erosion of disturbed surfaces such as abandoned airstrips.

The author stressed that plant establishment after disturbance will be very slow and that any revegetation attempts should use rapidly-growing species. Three species native to King Christian Island offer a combination of desirable characteristics. *Alopecurus alpinus, Phippsia algida,* and *Puccinellia vaginata* all have relatively rapid root elongation and replace their entire living root system over two or three growing seasons so that root damage during transplantation may be less costly to the plant than for species with longer-lived roots. *Alopecurus alpinus* roots penetrate both deeply and widely into the soil, adding to soil stability. Its rhizomes are capable of growing beneath hard dried surfaces thus allowing it to spread even in soils subject to extreme desiccation. In soil where cryoturbation or downslope movement jeopardizes plant establishment, root elasticity makes *Phippsia algida* and *Puccinellia vaginata* potentially valuable for revegetation. *Phippsia* is the preferable species for wet mobile soil, *Puccinellia vaginata* for the drier soils.

Seed collection for these three species is difficult, either because seeds fail to set or, if they do, are very difficult and tedious to collect. The author suggested that seed supplies may be more easily collected in less hostile habitats. For example, both *Phippsia* and *Alopecurus* grow lushly with advanced phenology in the sewage disposal area, Resolute Bay. Transplants also may be used for revegetation, particularly if *Alopecurus* is used. Plants of this species are abundant and appear tolerant of considerable disturbance. It is a natural colonizer of disturbed soils growing best on surfaces that are slightly rough (1 to 5 cm relief) rather than hard smooth disturbed sites. On

Continued ...

Bell, K.L. 1975. Continued

roughened surfaces, small chunks of soil containing *Alopecurus* tillers act as centres of growth with rhizomes spreading widely. Transplants of *Phippsia algida* would probably be useful in wet sites, especially where frost movements or solifluction are anticipated. Along streams, *Phippsia* established naturally from clods eroded from banks. Plants of both species are readily available from areas of local abundance. *Alopecurus*, with peak root growth early in the summer, should be transplanted as soon as possible after snowmelt; *Phippsia*, with more constant growth rates, could be transplanted somewhat later.

Two grasses useful for revegetation in the Mackenzie Delta region, *Arctagrostis latifolia* and *Calamagrostis canadensis* were being field tested on King Christian Island. These grasses are adapted to a longer growing season and are not likely to harden early enough for use in the High Arctic. However, seed sources from locations such as Cornwallis Island may be more suitable for conditions on King Christian Island. The author concluded that while further studies may determine methods of using species from low arctic regions for revegetation in polar semi-deserts, the species that presently seem most promising are ones native to the High Arctic.

1. BELL, K.L. and L.C. BLISS
2. 1973
3. Alpine disturbance studies: Olympic National Park, U.S.A.
4. Biological Conservation 5:25-32
5. Original
6. a. Washington; Coast Mountains

   b. Alpine; Roads

7. The effects of human trampling and road cut disturbance were assessed for an alpine area of Olympic National Park, State of Washington.

A road was constructed within alpine and high subalpine areas in 1937-38 and since construction plant invasion has been slow, diversity and cover of plants is much reduced and community composition is changed from the original. Three different habitats have resulted: (1) the roadcut itself into bedrock or scree; (2) the fill below the road; and (3) stable substrate at the base of the fill. The roadcut and the fill remain essentially bare with no soil development. Small pieces of turf have eroded from the upper cut and have initiated the only plant establishment. *Phlox diffusa* and *Calamagrostis purpurascens* are frequent in old turf while newly established plants tend to be *Achillea millefolium* ssp. *lanulosa* var. *alpicola* or *Phacelia sericea*. The stable substrate at the base of the fill had an unusually dense (96%) cover of *Juniperis communis* var. *montana, Festuca idahoensis* and the same *Phlox* and *Achillea*. Stability, deeper and later-melting snow and run-off from upslope all contribute moisture to these plants.

Plant cover in the scree above the road showed a 75% reduction and the fill below the road a 95% reduction when compared with undisturbed areas above the road.

Subalpine meadow cuts had much greater cover establishment particularly at lower elevations. Plant cover could probably be increased in alpine areas by transplanting sod blocks and adding surface mulch for erosion control.

The areas of stone-vegetation strips present have downslope movement greatest at the centre of the stone stripes. Movement is affected by the presence of vegetation and by slope angle. A movement of 3.5 4.5 cm/yr is a reasonable average and explains why steep slopes are

Continued ...

Bell, K.L. and L.C. Bliss. 1973. Continued

devoid of vegetation.

The impact of trampling on vegetation is dramatic. With the equivalent of 1,200 people walking once each over an area in four weeks, plant cover and annual net plant production were reduced to 2 to 5% of that in undisturbed areas.

Similar studies on Trail Ridge in the Colorado Rockies have indicated that after 25 years of visitor use, recovery to climax vegetation may take several hundred to 1,000 years.

1. BERDUSCO, R.J.

2. 1974

3. A case study and analysis of the reclamation of three surface coal mines in the Crowsnest Pass region of British Columbia.

4. University of British Columbia, Vancouver, B.C. B.S.F. Thesis. 76 p

5. Original

6. a. British Columbia; Rocky Mountains

   b. Alpine; Overburden

7. This thesis is a case study of the ecological, economic and social implications of reclamation of three relatively small surface coal mines in the Crowsnest Pass area carried out in 1973 by Kaiser Resources Ltd. Two of the mines, Erickson and Baldy mines, were abandoned in 1948 and 1956 respectively and were not subject to the Coal Mines Regulation Act, while the third mine, McGillivray, was subject to this act.

A variety of surficial deposits cover the mine area, ranging from ablation till at high elevations to gravel deposits, flood plains and alluvial fans in valley bottoms. Soils are podzolized grey wooded, brown podzolic and brown wooded, with pH ranges of 6.4 to 7.8 at altitudes from 3,600 to 4,500 ft, and pH of 5.2 to 7.0 at altitudes from 4500 to 6700 ft.

A large percentage of all three mines have slopes with south to west exposures. Also common to the three mines are the calcareous, coarse textured, well-drained soils which have physiological drought stress and which explains why these exposures are dominated by grass-shrub communities.

The first steps taken for revegetation were an analysis of aerial photographs and examination of the vegetation surrounding the mines to draw up a list of plant species represented. From this list, species used to revegetate the mine sites were chosen. The Canada Land Inventory classification for the area is prime big game range, and this was chosen as the goal for ultimate use of the rehabilitated area, along with re-establishment of the area's watershed and aesthetic functions.

A three-stage reclamation plan was carried out for each mine site: site preparation, seeding and planting.

At the McGillivray Mine (26 acres), extensive resloping was necessary to stabilize the soil, to control drainage and erosion and to provide a suitable growing medium. After resloping, a contour map of the mine was made to determine slope and aspect available for revegetation. North-facing

Continued ...

Berdusco, R.J. 1974. Continued

slopes were planted to coniferous species and south and southwest-facing slopes with shrubs. Grasses and legumes were also sown over the area except where slopes exceeded 30°.

Trees planted included black cottonwood, trembling aspen, Manitoba maple, European white birch (*Betula verrucosa*), lodgepole pine and Douglas-fir. Black cottonwood, Manitoba maple and aspen were reduced to shrub-like forms under exposure and browsing by animals. Grasses and legumes seeded were a diverse mixture of perennial species, with sweet clover as the nurse crop. Planting and seeding were carried out in early spring, the time of optimal soil moisture.

Grasses and legumes were sown at 44 lb/acre following fertilizer application of 212 lb/acre of N_{14} P_{14} K_7. Fertilizer and seed were applied with "cyclone" hand seeders, and buried by harrows dragged along the contour wherever possible. Trees and shrubs were planted by hand with mattocks. Planting stock was bare-root with the exception of black cottonwood where rooted cuttings and wildlings were used. Planting in favourable microsites was favoured instead of the conventional 6 x 6 spacing.

Preliminary assessment of results indicated 50% survival of coniferous species, 80% survival of deciduous species, and grasses and legumes well established. Total cost of revegetation (seeding, fertilizing, harrowing and planting) was $3774 for 26 acres, or $149/acre.

Unforseen problems were: (1) active erosion of the unvegetated headwall; (2) gulleying on the long, unbroken slope of the west side of the site; (3) browsing of newly planted stock resulted in uprooting of seedlings; (4) potential damage to vegetation in winter or early spring by recreational snowmobiles; (5) potential damage to seedlings on long, unbroken slopes as a result of snow creep.

The Erickson Mine was left with 30 acres of overburden dumps of steep erodible surfaces which after 25 years had little vegetation. Overburden dumps were resloped and a contour map prepared to show favourable areas for seeding and planting. The same tree, shrub and grass species were used as at the McGillivary site with the exception of lodgepole pine. Microsite variation did not occur on these resloped dumps, so shrubs and trees were planted at 10 x 10 spacing, and conifers on west to southwest slopes at 6 x 6 spacing.

Preliminary results indicated that there was 0% coniferous tree survival, 80% deciduous tree and shrub survival, and grass and legumes well established.

Costs of reclamation (seeding, fertilizing, harrowing and planting) were $3543, or $118/acre. Snowmobile traffic and snow creep were two potential problems for revegetation.

At the Baldy Pit, the study area was one long face of 37° slope after mining and a surface comprised mainly of fine-textured coal, with gullies eroding the slope. In the 25 years since abandonment, virtually no

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Berdusco, R.J. 1974. Continued

vegetation occurred at this site.

The first step of reclamation was to reduce the slope angle of the central and lower sections to a maximum of 25° but the material of the upper slope prevented resloping. Six 10-ft insloped benches were bulldozed to prevent gullying and to conserve soil moisture. Gully erosion was prevented, except for that which occurred in the interval between resloping and bench construction.

Revegetation of this mainly south exposed slope was with deciduous trees and shrubs. Grasses and legumes were planted with sweet clover again as a nurse crop, with all planting carried out in spring. Harrowing was carried out easily on the lower slopes and dragged across the slope where possible. Extra seed was sown on the upper, unharrowed slope where birds ate much seed.

Survival of trees and shrubs was estimated at 90%, and the grasses and legumes established only where the surface was harrowed. Total costs were $2469, with an average $165/acre.

The black soils and fine texture on a steep south-facing slope created temperature problems, some erosion, and poor water availability. Several plants exhibited sun-scald at the soil-air interface. Browsing by deer and elk was also a problem causing uprooted plants.

1. BERG, W.A.

2. 1974

3. Grasses and legumes for revegetation of disturbed subalpine areas.

4. In: Revegetation of High-Altitude Disturbed Lands, Proceedings of a Workshop at Fort Collins, Environmental Resources Centre, Information Series No. 10, Colorado State University, Fort Collins, Colorado, p 31-43

5. Original

6. a. Colorado; Rocky Mountains

   b. Alpine; Overburden, Roads, Tailings

7. Species selected for seeding should reflect long-term land use objectives and a knowledge of the growth characteristics, longevity, reproduction potential and special problems of each species. In this paper, species for subalpine areas are grouped according to their capability and their commercial availability, and for establishment on disturbed soil.

Species which usually establish well and have proven to be persistent in the subalpine zone include the foxtails (meadow and creeping) and smooth brome. The foxtails are probably the only commercially available species able to set viable seed in higher subalpine areas. Foxtail seed is fluffy and requires a carrier (rice hulls) in seed drills.

The "Manchar" variety of smooth bromegrass has proven particularly persistent probably because it is rhizomatous. Seedling vigour is good and seed is relatively inexpensive and easy to handle. Smooth bromegrass has a high nitrogen requirement and will dominate in stands if fertilized intensely.

Species which establish well but are not persistent in the subalpine zone include:

1. timothy - a bunchgrass good for broadcast seeding because of a round seed that catches in cracks; dies out after 5 to 6 yr.,longer in moist sites;

2. slender wheatgrass - a bunchgrass native to the subalpine, but commercial seed will not set viable seed and stands die out after 4 to 5 yr; local seed may last 10 yr and re-seed;

3. tall fescue - a less persistent bunchgrass with potential at lower elevations for heavy foot traffic areas;

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Berg, W.A. 1974. Continued

Several species show promise and may have a special use such as hard fescue, mountain brome, reed canarygrass and four wheatgrasses (intermediate, pubescent, streambank and western). A strongly rhizomatous ecotype of western wheatgrass has been found to invade disturbed soils and certain mill tailings in the subalpine region.

Legumes are particularly desirous on disturbed land deficient in nitrogen. The commercially available species for the upper subalpine zone are quite limited: alfalfa, white clover (better on moist sites at lower elevations), cicer milkvetch, birdsfoot trefoil, crownvetch and red and alsike clovers. Most have poor seedling vigour with the exception of alfalfa. Inoculation with the proper *Rhizobium* for each species is mandatory.

1. BERRY, C.B.

2. 1970

3. Revegetation program tailings pond dyke.

4. Great Canadian Oil Sands Limited. Reports One and Two. Unpublished Reports. Various paging.

5. Original

6. a. Alberta; Canadian Taiga

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. In these two preliminary accounts of revegetation trials on tailings ponds dykes of Great Canadian Oil Sands Limited, methods and species are outlined with a few interim observations and conclusions. The sands are alkaline in nature with pH varying from 7.0 to 9.0 and are devoid of major plant nutrients (nitrogen, phosphorus and potash). Trials were made on tailing sands alone, and tailing sands to which muskeg (peat) and black clay were added.

Results from the vegetation trials indicated that by themselves the tailing sands do not provide a medium for plant growth for several reasons: (1) low moisture retention capacity which increases the time required for seeds to germinate and plants to establish; (2) this slower growth provides no control on wind erosion of sand, especially on the crests of slopes; (3) the low moisture retention of the sand allows accelerated movement of moisture downslope and hastened leaching of plant nutrients.

The seed mixture consisted of 10 lb brome grass, 8 lb crested wheatgrass, 5 lb creeping red fescue, 5 lb white sweetclover and 5 lb of alsike clover; this mixture was applied at a rate of 300 lb/acre. Seed was broadcast and seedbeds were prepared by both harrowing and hand raking, to ensure coverage of the seed. Fertilizer, consisting of 8-24-24, was spread at the rate of 800 lb/acre.

The introduction of muskeg or muskeg and good clay (boulder till) improved the structure and water-holding capacity of the soil, reduced water movement downslope, increased the soil's ability to retain plant nutrients, increased the nitrogen content, reduced the high soil pH, accelerated seed germination and increased the plant survival rates.

Four specific recommendations were made: (1) selected muskeg must be spread on the sand slopes to a depth of 4 inches; (2) the muskeg must be disced into the soil; (3) seed and fertilizer must be spread by

Continued ...

Berry, C.B. 1970. Continued

hydroseeding; (4) an irrigation system is necessary to maintain a level of moisture that will ensure 75% germination rate and good growth.

To maintain the fertility level on the crests of tailing sand banks, four additional recommendations stipulate: (1) a reduction of the initial or preseeding fertilizer application of 8-24-24 to 400 lb/acre followed by applications of a fertilizer mixture of 34-0-0 and 8-24-24; (2) soil tests to provide frequent checks on plant nutrients, particularly nitrogen, phosphorus and potassium; (3) the application of water only as required when moisture levels drop below a level for good plant growth; (4) use of a slow release organic fertilizer such as Inilorganite.

The author observed that on one plot to which muskeg and clay were added, the seeding rate of 30 lb/acre produced too dense a cover for permanent thrifty forage and a reduced rate of seeding to 20 lb/acre might produce a better cover. Where muskeg was placed over sand, plants did not develop a strong rooting system. Packing of the soil after seeding may also hasten seed germination and plant development.

1. BERRY, C.B.

2. 1974

3. Reclamation of disturbed land. Revision 1. G.C.O.S. Lease Site Tar Island, Alberta.

4. Great Canadian Oil Sands Limited, Mine Engineering Department. 12 p

5. Original

6. a. Alberta; Canadian Taiga

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. This report updates reclamation plans and practices of an earlier report, *Reclamation of Disturbed Land,* and provides guidelines and a time schedule for reclamation projects in the G.C.O.S. lease area near Fort McMurray, Alberta.

The objectives of reclamation in this area are to return the land to an acceptable condition ecologically and aesthetically, and specifically to prevent wind and water erosion of sand dykes and overburden dumps. The proposed land use for dyke slopes and waste dumps is that they be developed as wildlife habitat and that dyke plateaus be developed for possible commercial enterprises.

In a schedule of revegetation, the immediate plan is to revegetate the outfacing slopes of the tailings dam comprising 71.5 acres. Testing of native plant species includes aspen, balsam poplar, willows, white birch and pin cherry. Past testing has shown that seedbed preparation by the addition of muskeg to sand, in a ratio of 1:1, will produce a vegetative cover without irrigation and will control wind erosion by the end of the first growing season and water erosion by the third growing season. Muskeg is spread downslope by a crawler type tractor to a depth of 4 inches and because of its high moisture content should be spread before freezing. A Howard Rotovator is used to till the muskeg into the sand. Packing was necessary for this seedbed after seeding.

Although hydroseeding was recommended in the first G.C.O.S. report, conventional seeding was recommended in this report. The conventional method is a Brillion grass seeder which can accomplish three functions at once: seeding, fertilizing and packing the sand. An area seeded with a Brillion grass seeder in 1972 showed better results through earlier and increased seed germination and more even distribution of grass and legume seeds compared to results from hydroseeding.

Continued ...

Berry, C.B. 1974. Continued

On the waste dump, the sloping sides were re-contoured to a slope ranging between 4:1 and 3:1. Benches are planned to reduce water erosion and facilitate revegetation. The soil of the waste dumps varies from a fine-textured, hard packed clay to sandy clay and clay plus muskeg. Hardpacked areas require deep (18 to 24 inch) tilling for air and water penetration followed by the addition of a 3 to 4 inch layer of coarse sand worked into the top layers to create a friable seedbed. A Rome disc plow is necessary for this operation because of the stoniness of the clay. For the same reason, hydroseeding will be necessary in this area.

The long range schedule of herbaceous revegetation and afforestation of the outer slopes and plateau depends on the construction schedule and whether a method for separating clay and bitumen from liquid tailings is developed.

Several areas are recommended for study and research. The first is how to provide a soil which will maintain plants with a minimum of maintenance for 8 to 10 years. To determine this, test plots should be established in vegetated areas to determine the following specific questions: the influence of tilling on the accumulation of organic matter in topsoil; the influence of grass and legume mixtures in various ratios for maintaining plant nutrients in the soil; the influence of rates of fertilization; and the evidence of salt accumulation in soil and its effect on plant growth. To prevent damage to freshly planted vegetation by wind and water erosion, various types of commercial soil stabilizers will be tested, such as SS 1 Asphalt Emulsion, Carasol and Hals 801. For afforestation planning, an inventory of woody vegetation present on the uncleared lease is recommended.

1. BESCHEL, R.E.
2. 1963
3. Observations on the time factor in interactions of permafrost and vegetation.
4. In: R.J.E. Brown, Editor, Proceedings of the first Canadian conference on permafrost, 17 and 18 April 1962. National Research Council, Ottawa. Technical Memorandum No. 76. p. 43-56
5. Original
6. a. Queen Elizabeth Islands; Canadian Tundra

   b. Arctic Islands; Roads

7. The author described natural revegetation of disturbed surfaces on an abandoned airstrip at Eureka on Ellesmere Island. An airstrip was constructed 5 km northeast of the weather station in 1947 by scraping the surface of a clay-silt plain. In 1951 this strip was abandoned and as early as 1953 the old airstrip stood out by its much denser vegetation cover.

There is no difference in level between the old airstrip and the surrounding area. The border has in parts a low ridge 30 cm high and a few meters wide which is very likely the material scraped from the runway. Ice wedges in the airstrip have melted and the polygons 20 to 30 m in diameter are often separated by ditches 2 to 3 m wide and 1 to 2 m deep in contrast to the furrows outside the runway which are depressed only 20 cm. The new ditches already possess a well developed vegetation cover consisting mostly of *Carex stans, Eriophorum scheuchzeri, Deschampsia brevifolia,* and *Equisetum arvense,* while the only common species in the shallow furrows outside of the airstrip is *Deschampsia.* Colonization of a different habitat by additional species is to be expected, but the increase in plant cover on the flat polygons is surprising. *Puccinellia angustata, Festuca brachyphylla, Alopecurus alpinus, Deschampsia brevifolia,* and *Salix arctica* are much more vigorously developed on the airstrip and cover 30 to 40% of the ground in sharp contrast to a scarce growth of the same dominant species covering only 5 to 10% of the area outside the airstrip.

Other workers had noted a rapid growth of cultivated plants in Alaska the first year after ground above permafrost had been stripped of its original vegetation. They relate it to a better water supply when the frozen ground thaws to greater depth. In later years, however, this increased productivity decreases. The author believed that at Eureka the same relationship should prevail. The unexpected continuing rapid

Continued ...

Beschel, R.E. 1963. Continued

growth may be caused by the removal of accumulated salt in the top layers of the soil by scraping. Under the very arid conditions of this area salt crusts are common on bare soil and may be more disadvantageous to plant growth than the low precipitation. In addition, delayed thawing caused by a denser vegetation cover reduces the run-off and distributes the water supply over a longer period. The denser vegetation may also retain more snow. Whatever the interaction of the various factors may be, the old airstrip at Eureka demonstrates that minor initial changes may produce substantial alterations in a few years where permafrost and vegetation interact.

1. BLASER, R.E.
2. 1963
3. Principles of making turf mixtures for roadside seedings.
4. Highway Research Record 23:79-84
5. Original
6. a. Virginia; Eastern Forest

   b. Southwestern Mackenzie, Southern Yukon; Roads

7. Germination, growth and survival of grasses and legumes vary by species and the microclimate in the seedling community. For this reason, a mix of several of the best-adapted varieties is recommended for the best chance of obtaining a good sod. The mix should be simple and not include more than four turf species. Mixes should also be tailored for date of planting and microclimatic differences associated with variations in steepness of slope and direction of exposure.

A mix also allows for the slow germination and establishment of some desirable perennial species and legumes, while faster germinating grasses or cereal crops provide the necessary erosion control while the others become established. Companion grasses also have a moderating effect on soil temperature, provide insulation, and improve soil moisture. Kentucky 31 fescue and bluegrass are enduring perennial sod covers; creeping red fescue, redtop and perennial ryegrass have aggressive seedling growth and faster sod establishment. Mixtures with Kentucky 31 fescue should not include aggressive companion grasses as this species is easy to establish because of its wide adaptation and good seedling vigour.

Crown vetch and Sericea lespedeza both have poor seedling vigour and are adversely affected by high nitrogen fertilization and heavy grass seeding. Low application rates of nitrogen and low seeding rates of companion grasses encourage better populations of these legumes. Low soil nitrogen is a common problem in grass maintenance. Urea formaldehyde is a slow-release nitrogen fertilizer commonly used for sod establishment.

1. BLISS, L.C.
2. 1958
3. Seed germination in arctic and alpine species.
4. Arctic 11:180-188
5. Original
6. a. Alaska, Wyoming; Alaskan Tundra, Rocky Mountains

   b. Alpine; Overburden, Roads, Tailings

7. Seeds collected from low arctic tundra of northern Alaska and from alpine areas of southeastern Wyoming were compared for viable germination. Viable seed was evident by many species in each region. No great differences were found in the average germination percentages of the species from arctic and alpine tundras, although a greater proportion of alpine species germinated.

Germination tests carried out in light and darkness indicated that some seeds germinate equally well in light and dark while germination of others is reduced in dark. The author suggested that arctic and alpine species which produce seeds capable of germinating equally well in light and dark are those in which the seeds are subject to burial. Duration of photoperiod may also play a role in the germination differences.

1. BLISS, L.C. and J.E. CANTLON
2. 1957
3. Succession on river alluvium in northern Alaska.
4. American Midland Naturalist 58:452-469
5. Original
6. a. Alaska; Alaskan Tundra

   b. Yukon Coast and Mackenzie Delta Region; Roads

7. Four communities were studied in 1953 representing a successional series from youngest to oldest and a progression from a stream channel to a terrace across a migrating meander of the Colville River on the arctic slope of Alaska. These communities were: (1) a pioneer stage characterized by perennial herbs, the most abundant of which were *Crepis nana, Erigeron purpureus, Epilobium latifolium,* three *Artemisia* sp., *Oxytropis* sp., *Astragalus alpinus* and *Lupinus arcticus*; (2) a vigourous willow stage dominated by feltleaf willow (*Salix alaxensis*); (3) a zone of deteriorating feltleaf willow with increasing cover of lower-statured green leaf willows, mosses and herbs; and (4) an alder-willow-heath type.

This succession takes place as a result of physical (allogenic) and biotic (autogenic) changes and each stage has quite different site conditions from other stages. The pioneer herb community is open but later becomes dense where silt and sand gather over river gravels. Soils are coarse and deeply thawing. With increased sedimentation and depth of the silt and sand mantle, the speed of thaw is slower. Fairly dense stands of *Artemesia* sp., *Lupinus arcticus, Agropyron sericeum, Poa lanata, Deschampsia caespitosa, Epilobium latifolium* and other forbs grow on the primarily coarse-textured deeply thawing soils. Among the less common species restricted to areas of deepest sand and silt are *Arctagrostis latifolia, Bromus pumpellianus* var. *arcticus* and *Hierochloe odorata*.

Mosses established in these perennial herb stands can cover 20 to 40% of the surface - mostly from the genera *Bryum, Dicranum, Dicranella* and *Encalypta*. Willow eventually invades this community as the depth of sand increases sufficiently. The tall feltleaf willow is ultimately replaced by other willow species, sedimentation continues during flood times and the soil thaws progressively slowly as the groundcover provides increased insulation.

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Bliss, L.C. and J.E. Cantlon. 1957. Continued

These alluvial habitats and vegetation have much in common with alluvial vegetation of central Alaska and with similar sites in non-tundra areas. Habitat conditions generally evident on floodplains include periodic flooding, fluctuating water table, absence of a surface organic layer, periodic erosion and deposition of light textured soil materials of moderate nutrient content. Almost all the floodplain species have deep root systems and are able to grow well on sites that are deeply thawed but which become fairly dry in the surficial layers. On the Alaskan Arctic Slope the pioneer vegetation decreases in the number of species progressing toward the coast and at higher elevations.

1. BLISS, L.C. and R.W. WEIN

2. 1972

3. Plant community responses to disturbances in the Western Canadian Arctic.

4. Canadian Journal of Botany 50:1097-1109

5. Original

6. a. Mackenzie District, Queen Elizabeth Islands; Canadian Tundra

   b. Mackenzie Delta Region, Arctic Islands; Roads

7. Several studies conducted in the MacKenzie Delta and the Arctic Archipelago describe and provide data on disturbances to plant communities from fire, seismic activity and spilled crude oil.

Changes in timing and technology of seismic activity have significantly reduced plant community disturbance from oil exploration. Wherever viable roots and rhizomes of shrubs, sedges and grasses remain in the disturbed soil, a 30 to 50% recovery in natural plant cover will occur in three to five years with subsidence restricted to areas of high ice content. If subsidence of 0.5 to 2 m has occurred, natural or man-induced revegetation can take place on the new surface but there is no indication that reseeding will prevent ground ice melt or subsidence.

Evidence of natural revegetation in the Mackenzie Delta region indicates that *Calamagrostis canadensis, Arctagrostis latifolia* var. *latifolia* and *Poa lanata* are pioneers of surface disturbed sites.

Planting trials conducted in 1970 with 16 species with different fertilizer combinations indicated: (1) seedling establishment was more rapid on peats but sustained growth was better on mineral soil when both were kept moist; (2) 100 kg/ha of elemental nitrogen and 200 kg/ha of phosphorus was the best fertilizer treatment; (3) early spring or late fall seeding was essential; and (4) best results in establishment and winter survival were derived from *Festuca rubra* (Arctared and Boreal varieties), *Poa pratensis* (Nugget variety), *Poa compressa* and *Phleum alpinum* equally well on peats and mineral soil. *Alopecurus pratense* grew better on mineral soil. Two annuals, *Avena sativa* and *Secale cereale* also grew well, although the latter was harvested by red-backed voles with implications for its survival or attraction as a winter food source.

Available nitrogen appears to limit plant growth of native species but phosphorus does not. Most nutrients are retained in the organic mat.

Continued ...

Bliss, L.C. and R.W. Wein. 1972. Continued

Removal of this layer seriously alters normal nutrient cycling and increases the need for fertilizers in revegetation.

The authors indicated that unless species or seed mixes can be sown into peats or unless mulches are added to mineral soil, plant establishment is difficult because many sites dry rapidly in summer when precipitation is low.

Preliminary work from the northern arctic islands indicates that surface rutting and scraping is less detrimental biologically than in the Low Arctic. Less thaw of permafrost occurs than in the Mackenzie Delta region, although wet lowland areas are subject to disturbance in summer as in the Delta. The different plant community - topographic - soil - ground ice landscape units respond differentially to different surface disturbances in both the Low and High Arctic.

1. BLISS, L.C. and R.W. WEIN, Editors

2. 1972

3. Botanical studies of natural and man-modified habitats in the eastern Mackenzie Delta region and the Arctic Islands.

4. Arctic Land Use Research Programme, Indian and Northern Affairs, Ottawa. ALUR 71-72-14. 288 p

5. Original

6. a. Mackenzie District, Queen Elizabeth Islands; Canadian Tundra

   b. Mackenzie Delta Region, Arctic Islands; Roads

7. At the conclusion of this report, which contains articles by Babb, Hernandez and Younkin annotated separately in this bibliography, several specific conclusions and recommendations, as listed below, were made regarding plant invasion of man-modified habitats in the Canadian Low and High Arctic.

The landscape units identified show such a wide diversity of characteristics that the specific area must be known to predict the response to a given disturbance. Land officers and future researchers should be aware of these differences.

Agronomic species that have shown promise for re-seeding are timothy, meadow foxtail, red fescue, Kentucky bluegrass and Canada bluegrass.

Seed mixes that contain those species that show good growth the first year and those that are winter hardy will ensure a better ground cover.

Seeding should be conducted immediately after the disturbance has occurred or as early in the spring as possible.

Fertility programs should include both nitrogen and phosphorus fertilizer up to rates of 100 kg/ha (100 lb/acre).

Based upon present information, re-seeding of surface-disturbed areas in the High Arctic appears to have little potential. A nitrogen and phosphorus fertilizer will stimulate plant growth and may be the only practical approach to increases in plant cover, provided some species have survived.

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Bliss, L.C. and R.W. Wein, Editors. 1972. Continued

Generalization for the whole arctic, regarding natural and artificial re-seeding success and the impact of disturbance, is not possible. The authors also indicate that it is not possible to predict the influence of disturbance, seeding success and required fertilizer levels in upland and lowland sites within an area of a few hectares.

The principal species that naturally invade seismic lines are *Arctagrostis latifolia, Calamagrostis canadensis, Poa lanata, Luzula confusa* and *Senecio congestus* with *Arctophila fulva, Eriophorum angustifolium* and *Carex aquatilis* in wetter areas.

In the Low Arctic and High Arctic, low soil temperatures exert a major limitation on plant growth; available nitrogen is low because of slow release attributable to the low soil temperatures which suppress microbial activity. Native species respond to nitrogen conditions but as phosphorus is readily available in native soils, commercial phosphorus fertilizers have less influence. Introduced grasses respond more readily to phosphorus. A combination of 100 kg/ha each of nitrogen and phosphorus gives the best results for introduced grasses on mineral soils, and phosphorus alone is best for organic soils. Response of introduced grasses to nitrogen alone is poor. Seed head production is also increased by the application of nitrogen and/or phosphorus.

In the tests reported in this volume, timothy, meadow foxtail and slender wheatgrass provided the best height growth while red fescue, Kentucky bluegrass and Canada bluegrass gave the best groundcover. The best seed mixes would include reed canarygrass and orchardgrass to provide a good nurse crop the first year, along with some of the above-listed species for long term revegetation.

1. BOLSTAD, R.

2. 1971

3. Catline rehabilitation and restoration.

4. In: C.W. Slaughter, R.J. Barney and G.M. Hansen, Editors, Fire in the Northern Environment - A Symposium, Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Portland, Oregon, p 107-116

5. Original

6. a. Alaska; Central Alaska Taiga, Southern Alaska Taiga

   b. Southern Yukon, Northern Yukon; Roads

7. Severe erosion on catlines (bulldozer-constructed firelines) has occurred on permafrost terrain in Alaska. Attempts to control this erosion have focussed on the joint use of water-barring techniques and seeding treatments.

Seed was applied to permafrost and non-permafrost disturbances in fall, using a 2:1 ratio of Manchar smooth brome and Kentucky bluegrass at a rate of 40 lb/acre. Seed was also applied in spring as a grass mixture which included reed canarygrass, timothy, sweet clover (white and yellow), rye, Manchar smooth brome and Kentucky bluegrass, also at 40 lb/acre. Observations were made after one growing season.

Better seed response occurred with fall seeding on both permafrost and non-permafrost sites, with best response from bromegrass. Seed growth was more successful on the water-saturated soil of permafrost plots. Lack of moisture and an absence of soil coverage of seed were the limiting factors for development on non-permafrost soils.

Drilling of seed is preferred over aerial seeding for non-permafrost soils, but aerial seeding is effective for permafrost areas. Fertilizer of the 20-20-10 pellet-form produced better growth response than non-fertilized plots on both the permafrost and non-permafrost soils.

On a control permafrost plot with no treatment, natural revegetation had started with sedges, *Calamagrostis*, *Eriophorum* and *Equisetum* plus small amounts of moss. After one growing season, these plants were small and did not prevent erosion.

Standard water bars and berm dikes constructed at 30- to 50-yd intervals on sloping terrain were effective in checking erosion. These should be constructed immediately after a fire on permafrost soil prior to severe melt. Vegetated check-dams were ineffective on permafrost soils because ice melt underneath these dams caused severe erosion.

1. BRADSHAW, A.D.

2. 1952

3. Populations of *Agrostis tenuis* resistant to lead and zinc poisoning.

4. Nature 169:1098

5. Original

6. a. Wales; British Forest

   b. Yukon and Northwest Territories; Tailings

7. In a study of *Agrostis tenuis* in the Aberystwyth region of Wales, samples of 60 separate tillers were taken from various habitats, including pastureland and a dis-used lead mine at Goginan, at least 100 years old, where the soil contained approximately 1% lead and 0.03% zinc. *Agrostis tenuis* was the only plant life on the mine soil.

Some of the tillers were transplanted to mine soil and to normal soil. On the normal soil, the sample from the mine was distinctly smaller and grew more slowly. On the mine soil, the mine sample of tillers grew normally. In contrast, a pasture sample made no growth; 50% of these tillers were dead after three months and they possessed misshapen roots rarely more than 2 mm long.

The author indicated that there was no indication of any change in resistance having occurred.

1. BRADSHAW, A.D., T.S. McNEILLY and R.P.G. GREGORY
2. 1965
3. Industrialization, evolution and the development of heavy metal tolerance in plants.
4. In: G.T. Goodman, R.W. Edwards and J.M. Lambert (Editors), Ecology and the Industrial Society. British Ecological Society Symposium Number 5, John Wiley and Sons, New York. p. 327-343
5. Original
6. a. Wales; British Forest

   b. Yukon and Northwest Territories; Overburden, Tailings

7. In some man-made environments rapid colonization by plants occurs and a new vegetation builds up different from the old; in other cases the habitat is not so satisfactory but the passage of time is all that is necessary to allow natural weathering to improve the soil; and in other cases colonization is virtually non-existent because of toxic substances. What happens to these latter areas? Although man can do something about them, perhaps at great expense, the authors have designed research to determine whether nature can do anything to colonize such areas.

If one looks at natural habitats throughout the world it is possible to find many which are as extreme as the poorest and most extreme of man-made habitats: habitats with high sulphide, high nickel, high chromium, low pH or high salinity. The significant thing about these habitats is that they are rarely, if ever, bare and devoid of plants. This is the author's first fundamental point. The processes of evolution inevitably lead to new adapted types which colonize what is not already occupied. If a niche is vacant, evolutionary processes will lead to its colonization.

The second fundamental point is that we do not need to think of evolution in terms of millenia. This long time scale is necessary when we think about the history of life but it is not required for the processes of evolution within a species.

These points led the authors to investigate whether there are detectable evolutionary changes in plant populations that are invading the habitats made by man. This was done through studies of metal tolerance in *Agrostis tenuis* that is able to grow on mining sites high in lead, zinc, nickel, and copper, around Bangor, Wales. They found that populations of *Agrostis tenuis* in mid-Wales found growing on disused lead mines all possessed high levels of tolerance to lead. It could be imagined that tolerance to lead might also imply a tolerance to other metals such as

Continued ...

Bradshaw, A.D., T.S. McNeilly and R.P.G. Gregory. 1965. Continued

copper, zinc or nickel, but this is not so. A population tolerant of one metal was not tolerant of another unless the second was also present in its original habitat.

It was found that there is no significant difference in the amount of toxic metal taken up by a tolerant plant as opposed to non-tolerant plants. The metal in question must therefore be rendered innocuous within the plant itself.

The authors made a distinction between their findings and the concept of ecotypes. It is well known that a species may become differentiated into distinct populations (ecotypes) adapted to particular environments. Many of such changes seem to have occurred as a result of the species occupying such habitats; they do not appear to be the cause of the species occupying such habitats. However in the case of the evolution of metal tolerance in *Agrostis*, this is not so. Colonization of contaminated areas is only possible as a result of evolutionary changes; evolution is therefore the cause and not the effect of colonization.

It is pointed out that the industrial environment is not something special; it is just another environment. It may be somewhat extreme, but it is not necessarily beyond the ultimate inherent adaptive capabilities of some species. If the environment is severe, selection pressures will be high. Since the environment is new the variation in adaptation to it will not already have been exploited by natural selection. Taking these two arguments together it can be seen that rapid and spectacular examples of evolution are likely to occur in industrial environments. Examinations of the population changes that may occur in adaptation to industrial effects, whether these are metal contamination, herbicide, air pollution, or anything else, are likely to be very rewarding.

1. BRINK, V.C.

2. 1974

3. A summary of comments on grasses and legumes for land reclamation.

4. In: Land reclamation short course, sponsored by Faculty of Forestry, University of British Columbia, Centre for Continuing Education, University of British Columbia, and Mining Association of British Columbia. Various paging

5. Original

6. a. British Columbia; Coastal, Rocky Mountains

   b. Southern Yukon; Overburden, Roads

7. The author pointed out that in the United States there are 12 plant materials centers where adaptation of both native and alien plant species are studied for reclamation and production purposes, but in Canada there are no well organized plant material centers. The new plant materials center at Palmer, Alaska, is an example of the kind of facility that is lacking in Canada.

The objectives in obtaining species for production agriculture are not necessarily those for reclamation. The tendency of the agricultural selection is to favour high dry matter yield and local adaptation; this usually leads to a narrow genetic base. For reclamation where habitat is usually diversifed, a broader genetic base is often desirable and competitive ability rather than yield is of relatively greater importance.

There are hundreds of species and varieties from which to choose and to choose well is both a science and an art. The author presented a rough grouping of plant materials for reclamation according to the following categories:

(a) Wetland species

reed canary grass
meadow foxtail
barnyard grass
manna grass

(b) Dryland species

crested wheatgrass
stream bank wheatgrass
Russian wild ryegrass
tall wheatgrass
intermediate wheatgrass
bluebunch wheatgrass

Continued ...

Brink, V.C. 1974. Continued

(c) Humid and subhumid species

- smooth brome
- orchard grass
- annual and perennial ryegrasses
- fescues (tall, meadow, fine)
- bentgrasses (red top and others)
- timothy
- bluegrasses (Kentucky bluegrass, Canada bluegrass, Sherman bluegrass)
- tall catgrasses

(d) Legumes

- alfalfa, sainfoin
- sweet clover
- clovers (red, alsike and white)
- birdsfoot trefoil
- crown vetch
- annuals (peavines, vetches)
- dryland legumes (Cicer milkvetch)

1. BROWN, R.W. and R.S. JOHNSTON

2. 1976

3. Revegetation of an alpine mine disturbance: Beartooth Plateau, Montana.

4. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah. Research Note INT-206. 8 p

5. Original

6. a. Montana; Rocky Mountain

   b. Alpine; Overburden

7. This report summarizes first-year results of revegetation research of an alpine mine disturbance at the McLaren Mine on the Beartooth Plateau, 8 km north of Cooke City, at an elevation of 2,950 m on a generally southwest exposure.

Native species were better adapted for revegetation than introduced species. Native species were tufted hairgrass (*Deschampsia caespitosa*), alpine bluegrass (*Poa alpina*), alpine timothy (*Phleum alpinum*), spike trisetum (*Trisetum spicatum*), slender wheatgrass (*Agropyron trachycaulum*), spreading wheatgrass (*Agropyron scribneri*), woolly pussytoes (*Antennaria lanata*), mountain dryad (*Dryas octopetala*) and sedge (*Carex paysonis*). Density of native species was significantly higher than introduced species under all treatments (with and without topsoil and with and without fertilizer). Native species proved more responsive to fertilizer than introduced species on both soils.

Transplanting of woolly pussytoes, sedge, tufted hairgrass and alpine bluegrass was also tried. All transplants survived and were actively growing after one year. Mature plants had extensive root systems and crown development and could tolerate micro-environmental stress better than seedlings. Use of transplants may insure rapid plant establishment and development and offer a highly successful alternative to seeding. However, it is impractical to use transplants for an immediate, complete plant cover. The rate of lateral spread of transplants is little known. Little research has been done on the combined use of seeding plus transplants, and some erosion is possible on unprotected surfaces between transplants until lateral growth occurs. If native species are used, there is a need to develop nurseries for large-scale production of plants and seeds.

1. BRUMMITT, R.A.

2. 1976

3. Seeding of subsoils 1969-1975. Final Report.

4. Wisconsin Department of Transportation, Division of Highways, Section 7. Research Report 0092-01-71. 16 p

5. Original

6. a. Wisconsin; Eastern Forest

   b. Southwestern Mackenzie, Southern Yukon; Roads

7. Field plots on two subsoils in northern Wisconsin were planted with five different seed mixtures and five fertilizer combinations. The objective was to eliminate the expense of placing topsoil on highway backslopes. The two subsoils chosen were the Iron River glacial till consisting of silty sand with some gravel and boulders and the Stambaugh outwash material of clean sand.

Slopes were prepared by raking after grading and seeds were spread by a hand operated cyclone seeder. Mulch consisting of straw (2 tons/acre or 92 lb/1,000 ft^2) was spread by hand on most plots and anchored by a grid system of 10-ft spaced twine attached to pegs. Some test plots received a fertilizer application in the second year.

Based on the results, a satisfactory groundcover can be established on native subsoils. The Wisconsin Department of Transportation seed mix No. 2 (15% 21# Kentucky bluegrass, 55% creeping red fescue, 5% redtop, 10% perennial ryegrass and 15% white clover) is designed for droughty soils. It provided good groundcover on the silty sand subsoil with a fertilizer application of 10-10-10 applied at 10 lb/1,000 ft^2. A second application of fertilizer in the following year did not provide enough benefit to be standard practice, but benefit in growth was obtained from a slow release 38-0-0 fertilizer.

The white clover of the above seed mix did not grow well and should be replaced by Empire birdsfoot trefoil sown alone or in a seed mix. Birdsfoot trefoil produced a good cover on both subsoils and performed exceptionally well on the sandy suboil. This plant is slow to germinate but once established provides a good cover. After freezing, the resulting brown mat remains but because growth does not resume until late in spring it is best used in a seed mix. Seeding of birdsfoot trefoil is best with a filler to assure proper distribution as the seeds are very small.

Continued ...

Brummitt, R.A. 1976. Continued

One fertilizer tested, a slow release nitrogen fertilizer (38-0-0) applied at 8 lb/1,000 ft^2, improved growth and is recommended for use with the above seed mix on subsoils.

Mulching is considered essential for erosion control and improved growing conditions. Considerable erosion occurred on one un-mulched plot over a period of 2 months.

1. BUREAU OF LAND MANAGEMENT

2. 1973

3. Influence of man-caused surface disturbance in permafrost areas of Alaska.

4. Bureau of Land Management, U.S. Department of the Interior, Special Committee Assigned by State Director of Alaska, Fairbanks, Alaska. Unpublished Report. 19 p

5. Original

6. a. Alaska; Central Alaska Taiga, Southern Alaska Taiga, Alaskan Tundra

   b. Alpine, Northern Yukon, Yukon Coast; Roads

7. Most significant surface disturbances in permafrost areas of Alaska are a result of off-road vehicles, wildfire control activities, recreation activities, mining activities, seismograph exploration, rights-of-way development and surveying activities. Where surface disturbance damages the organic mat the result is thawing of the subsurface material. The effects of disturbance are soil erosion, decreased water quality, lower aesthetic values and reduced access.

Methods to control the effects of surface disturbance include the following rehabilitation steps:

1. start rehabilitation as soon as possible;

2. use drainage control structures to prevent water accumulation which increases the thawing rate of ground ice;

3. seed disturbed surfaces immediately after disturbance using such recommended species as Durar hard fescue, Arctared red fescue, meadow foxtail, and Nugget Kentucky bluegrass, with the following grasses used for quick cover - Illinois redtop for the North Slope, Polar bromegrass and Engmo timothy for other critical areas;

4. seed at rates of 15 to 35 lb/acre, 35 to 50 lb/acre for Illinois redtop, Polar bromegrass and Engmo timothy;

5. fertilize at seeding time (350 lb 18-46-0/acre) with a second application the following year of 20 lb N + 30 lb P/acre;

6. transplant brush and trees for erosion control and for screening where it is desirable for some sites;

Continued ...

Bureau of Land Management. 1973. Continued

7. use aerial spraying of fertilizer in preference to ground applied treatments;

8. artificial insulation (excelsior blankets, wood chips, slash, sawdust or styrofoam) can be used to retard or prevent ground ice thawing in localized problem areas.

Land management goals in permafrost areas, implemented through the Bureau of Land Management in Alaska are: to identify thaw-unstable permafrost areas and to zone these for strict management control; to zone other areas for development and resource use with management control of surface disturbance; and to rehabilitate all damaged areas. Special emphasis is placed on control of all resource uses in critical permafrost areas, which are those areas on fine soils with high ice content. Several techniques are listed, mostly related to control of off-road vehicles. There is also a recommendation for an erosion control contingency plan that would include water bars at specified intervals on sloping ground, selection of acceptable seed and plants, and choice of fertilizer grade and application rates.

1. CANADIAN ARCTIC GAS PIPELINE LIMITED
2. 1974
3. Responses to Pipeline Application Assessment Group requests for supplementary information.
4. Canadian Arctic Gas Pipeline Limited, Toronto. p. 31-1 to 34-2
5. Original
6. a. Mackenzie District; Canadian Taiga

   b. Central Mackenzie, Mackenzie Delta Region, Yukon Coast; Roads

7. This volume contained the applicant's answers to questions that had been posed by the federal government's Pipeline Application Assessment Group on criteria for revegetation procedures, revegetation specifications, replacement and revegetation of tundra, and revegetation using erosion-control mats.

The applicant was requested to explain the criteria by which specific seed mixes were proposed for specific terrain types along the projected pipeline route. For the purpose of assigning revegetation specifications during the early planning stages of this project, three general drainage classes were recognized: dry, excessively drained; moist, moderately to well drained; and wet, poorly drained. Almost the same combination of species for reseeding was proposed for each of these three general moisture classes, but the rate of seeding would be varied, as shown in the table below. For example, Revenue slender wheatgrass was specified at 10 lb/acre on dry sites, 2.5 lb/acre on moist sites, and dropped completely for wet sites.

The rationale used in developing the specifications was to emphasize the varieties best adapted to the soil conditions identified under site description, by increasing the rate of application of those varieties. Due to the natural variability in drainage conditions, and the variation in drainage conditions over a pipeline right-of-way, other varieties remain in the mix to provide the necessary amplitude and genetic potential to colonize the range of microhabitat conditions.

Specifications for right-of-way revegetation north of Travaillant Lake were as follows:

Continued ...

Canadian Arctic Gas Pipeline Limited. 1974. Continued

SITE	SPECIFICATION	
Dry, excessively drained	Arctared creeping red fescue	- 10 lb/ac
	Nugget Kentucky bluegrass	- 10 lb/ac
	Meadow foxtail	- 5 lb/ac
	Revenue slender wheatgrass	- 10 lb/ac
	Frontier reed canarygrass	- 5 lb/ac
	Engmo timothy	5 lb/ac
	Native grasses	- 5 lb/ac
Moist, moderately well to well drained	Arctared creeping red fescue	- 10 lb/ac
	Nugget Kentucky bluegrass	- 10 lb/ac
	Meadow foxtail	- 5 lb/ac
	Revenue slender wheatgrass	- 2.5 lb/ac
	Frontier reed canarygrass	- 10 lb/ac
	Engmo timothy	- 10 lb/ac
	Native grasses	- 2.5 lb/ac
Wet, poorly drained	Arctared creeping red fescue	- 10 lb/ac
	Nugget Kentucky bluegrass	- 10 lb/ac
	Meadow foxtail	- 10 lb/ac
	Frontier reed canarygrass	- 10 lb/ac
	Engmo timothy	- 10 lb/ac
	Native grasses	- 2.5 lb/ac

The basic approach proposed for revegetation of the pipeline right-of-way is to rely on seeding. The applicant viewed the technique of stripping and replacing tundra vegetation as supplementary to seeding.

The objectives of assisting the revegetation of sloping terrain through the use of mats are: first, to prevent the erosion of surface materials containing the seed during the interim between seeding and seed establishment; and secondly, to provide a mulch for the retention of moisture for the promotion of rapid germination. The practice is commonly used in Canada and the United States for stabilizing and revegetating highway cuts and backslopes. The same principles apply to the Applicant's project; only the plant species and varieties will differ.

The matting procedures proposed by the applicant would depend on the type of matting used. The seed and fertilizer would be applied first, using a helicopter and bucket if non-seeded matting is used (wood excelsior mat or jute netting). This would not be required if a preseeded mat is used. The matting would then be rolled out starting at the top of the slope and running it downhill. The mat would be held in place using wire staples, supplemented with cuttings, where plantings are desirable. The slope would be seeded and matting stapled in place as early in the spring as possible.

It was estimated that the time required by an experienced crew to lay and staple matting would be about 32 man-hours per acre.

1. CHADWICK, M.J.

2. 1974

3. Variation in the chemical characteristics of colliery spoil and its relation to vegetational establishment.

4. In: Green Colliery Spoil Banks in the Ruhr, International Special Congress, Mine Spoil Heaps in the Ruhr and their Integration in the Landscape, Siedlungsverbandes Ruhrkolenbezirk, Essen, Germany, p 22-25

5. Original

6. a. England; British Forest

   b. Southern Yukon; Overburden

7. Almost all attempts to integrate mine spoils into the landscape rely on the establishment of vegetation, the success of which is affected by the variability of spoil chemical characteristics. This variation occurs between tips, spatially within a single tip at one time, and temporarily within a tip at one location.

Analyses of six colliery spoils in Yorkshire serve as an example. The variation in spoil chemical characteristics is attributed to the mineral content, particularly pyrites or marcasite and the carbonate mineral ankerite. In five spoils, significant differences were found for pH, potassium, aluminum and iron. Two spoils were found deficient in nutrients with no evidence of toxicities, three were toxic and a sixth was intermediate.

Spoils can be chemically heterogeneous and this can be related to success of vegetation establishment. Application of lime alone to certain spoils raised the spoil pH but reduced the level of available phosphorus when contrasted with a control plot. Application of lime plus N P K fertilizer produced higher pH and phosphorus values so that grasses (*Agrostis tenuis* and *Festuca rubra*) survived after three years while *Lolium perenne* died after initial establishment.

It is essential that spoil chemical characteristics and their variability be understood. Advance analyses can establish the variation in chemical content and the nutritionally limiting factors. This knowledge, together with a knowledge of the mineral nutrition preferences of the species available, minimizes reclamation failure.

1. CLEBSCH, E.E.C. and W.D. BILLINGS

2. 1976

3. Seed germination and vivipary from a latitudinal series of populations of the arctic-alpine grass *Trisetum spicatum*.

4. Arctic and Alpine Research 8:255-262

5. Original

6. a. Alaska, Alberta, Wyoming, New Zealand; Central Alaska Taiga, Rocky Mountains

   b. Alpine; Roads

7. Two of the most critical aspects of tundra plant life are the process of germination and the period of establishment. In this study, seed germination and vivipary of *Trisetum spicatum* were related to temperature, light and soil factors. For this purpose seed was used from various locations in North America with latitudes ranging from 41° N (Wyoming) to 70° N (Alaska) plus two locations in the Old Man Range of New Zealand (45° S).

It was found that seed from populations of lower latitudes reached maximum germination more slowly but at higher temperatures than seeds from higher latitudes. Germination in high latitude populations was found to be light-stimulated while low latitude populations are dark-stimulated regardless of the thermal regime. Replication of arctic and alpine conditions indicated that germination was much slower for these conditions also.

A favourable temperature for the germination of seeds of most populations was 20° C. Most northerly populations germinated first at 20° C. For two locations from Highwood Pass, Alberta, one alpine and one subalpine, the alpine seeds started growth at 20° C on the fourth day while the subalpine seed started growth at 30° C on the third day. Seed germination in each of these populations was adapted to the temperature environment of the population's elevation.

Vivipary, the development of vegetative shoots among the reproductive organs of grasses, was common during the greenhouse and controlled-chamber tests with *Trisetum* populations but is not known from native populations. The factors causing vivipary have not been isolated.

There is also evidence of ecotypic differentiation among the various populations in germination responses to temperature and light, and in the development of viviparous plantlets under controlled conditions. Germination in continuous light is higher for the various seed locations than germination in continuous darkness for the northern populations.

1. COMMISSION COUNSEL TO THE MACKENZIE VALLEY PIPELINE INQUIRY

2. 1976

3. Commission Counsel submissions.

4. Unpublished draft document submitted to I.G. Waddell, Special Counsel, Mackenzie Valley Pipeline Inquiry, Ottawa. Various paging.

5. Original

6. a. Mackenzie District; Canadian Tundra

   b. Central Mackenzie, Mackenzie Delta Region, Yukon Coast; Roads

7. This draft document prepared by the Commission Counsel to the Mackenzie Valley Pipeline Inquiry consists of material released to the Inquiry to assist in the final argument and as a basis for discussion. Several separate presentations, each with a group of recommendations, focus on socio-economic issues, protection of the environment and land, and project design and construction.

One section included in the description of the pipeline and facilities outlines Commission Counsel's position on revegetation. The general recommendation is that the pipeline company holding permits to build a gas pipeline in the Mackenzie Valley region shall revegetate all disturbed land surfaces resulting from construction, operation and maintenance of the pipeline for the primary purpose of controlling erosion. Secondary objectives should be the re-establishment of native vegetation and the lessening of aesthetic impact.

It is recognized that the vegetative cover, the underlying organic mat and extensive network of roots are vital to terrain stability. Removal of these in permafrost areas can change the soil thermal regime, thereby increasing the active layer depth in summer and causing permafrost degradation. Plant cover in permafrost and non-permafrost areas prevents wind erosion and sheet, rill and gully erosion. Removal of the plant cover can set in motion such erosion processes. Revegetation of disturbed areas can control erosion only if done in conjunction with appropriate drainage control procedures. Restoration of permafrost after degradation cannot be achieved by newly established vegetation in the short term. Control of permafrost degradation must depend on non-biological means, a fact recognized by the present applicants.

Continued ...

Commission Counsel to the Mackenzie Valley Pipeline Inquiry. 1976.
Continued.

The two gas pipeline applicants have similar objectives for their proposed revegetation programs - erosion control by re-establishing natural plant communities. However, they proposed different methods to accomplish this. Arctic Gas plans to rely on agronomic varieties of grass for groundcover to control sheet and rill erosion, with native species having a secondary role. For slopes, shrub cuttings are planned and seed of two native grasses, *Calamagrostis canadensis* and *Arctagrostis latifolia*, will constitute some part of the seed mix. Foothills Pipeline Company plans to use native species with greater reliance on vegetative methods, including cuttings.

Both plans are dependent on a stable soil surface and neither applicant has demonstrated that this can be done everywhere, especially on slopes or cuts in ice-rich soils. Commission Counsel suggested that a large-scale test of proposed revegetation procedures is required for slopes with high erosion potential. Both applicants recognize the necessity for follow-up revegetation. It was also recognized that since most such procedures occur in summer there could be a potential conflict with wildlife. Priorities should be given to revegetating those areas most susceptible to erosion and revegetation should be conducted at a time appropriate to establishment.

The specific recommendations of Commission Counsel regarding revegetation are given below as presented in the original document.

> 1. Revegetation shall be planned and implemented as a complement to other drainage and erosion control measures rather than as an end in itself. First priority shall be given to areas where there is a high potential for erosion and major concerns over the environmental impact of erosion.
>
> The Company will ensure that revegetation (together with the necessary clean-up, re-grading, preparation of drainage and erosion control structures etc.) is completed promptly after termination of pipeline construction activity or other land-use of the site.
>
> To this end priority will be placed by the Company on the manpower, logistic and supply requirements of the revegetation program needed to meet the planned revegetation schedule.
>
> 2. The Company shall, as part of its preliminary design, demonstrate to the Agency by an approved field test or tests in the project area the suitability of its proposed revegetation procedures for the control of erosion on slopes and cuts.
>
> 3. The Company shall, at the design review stage, submit to the Agency its general plans for revegetation of the right-of-way and other disturbed areas. This plan shall indicate the kinds of seed mixtures and where they will be used, the vegetative methods to be

Continued ...

Commission Counsel to the Mackenzie Valley Pipeline Inquiry. 1976. Continued.

used and where, the amount and type of fertilizer, the types of equipment and their application and timing. The appropriate documentary evidence in support of these procedures shall also be included.

4. The Company shall submit to the Agency following the submission of its general plan a specific revegetation plan for each spread detailing manpower requirements and training, logistics, the seed mixes to be used and their rates of application, fertilizer type(s) and rates of application, methods and timing of application, vegetative methods and their application, expected follow-up, revegetation requirements, and procedures to be applied to minimize environmental impacts. These revegetation plans shall also demonstrate how the procedures and the seed-mixes and fertilizer will be adjusted in keeping with changes in topography, soil and drainage.

5. Where site-specific erosion control plans are necessary, the Company shall include the required revegetation procedures as a specific component of this plan.

Information shall be provided to the Agency on the source(s) of the plant material required for revegetation, manpower and aircraft requirements for the collection and placement of the plant material, support camp location, timing, and potential conflicts with wildlife population.

6. The Company shall, as an integral component of its initial revegetation program, monitor the short term success and shall repeat the revegetation measures where required until they are successful. The control of erosion shall be the primary objective of such follow-up revegetation; aesthetic considerations shall be secondary.

7. The Company shall monitor, as a part of its operations and maintenance program, the long term success of its revegetation program. Supplementary seeding will be limited to that required for the control of erosion and will not be allowed for only aesthetic or cosmetic reasons. This approach will limit the long term persistence of non-native species along the right-of-way and will encourage the re-establishment of native plant species.

8. The Company shall ensure that any requirements for summer revegetation, whether initial or supplementary, integrate both the needs of the plants for establishment and the avoidance, where possible, of conflicts with wildlife.

1. COOK, C.W.
2. 1976
3. Surface-mine rehabilitation in the American West.
4. Environmental Conservation 3:179-183
5. Original
6. a. United States; Grasslands, Great Basin, Rocky Mountains

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. Rehabilitation plans for surface-mined areas should be as detailed as possible, should be prepared as part of the over-all pre-mining plan and should be part of the agreement or contract between the lessee and lessor. The desired information for preparation of a well-planned rehabilitation program includes:

1. a topographic map of the area before mining to illustrate terrain formation which will also assist in reconfiguration of the overburden after mining;

2. a soil series map to describe the physical and chemical features of the topsoil and sub-soil, and a statement of herbage production potential;

3. a vegetation-cover map which identifies the species present (and possibly suitable for revegetation);

4. a description of the wildlife present in the proposed mining area;

5. a description of the prevailing climatic conditions (annual amount, form and season of precipitation, and wind velocity) which determine the tolerable slope angle and texture of topsoil.

Information to be included in the reclamation plan should also identify the area to be mined, the prevailing vegetation type and the potential for rapid and complete rehabilitation. When the spoil material is reconfigured, it should be characterized as to ecological response-unit (a homogeneous soil and plant community that will respond in a more or less similar manner to treatment and management), a characterization which takes account of such features as aspect, slope, drainage and altitudinal differences. Recommended information and procedures for a reclamation plan should include:

Continued ...

Cook, C.W. 1976. Continued

1. Identify the chemical and physical characteristics of the geological strata forming the overburden so that toxic material can be buried deeply and not allowed to surface.

2. Identification of topsoil or plant growth medium characteristics (organic content, textural limitations, salt threshold, pH value).

3. The means of seedbed preparation and construction of water-holding structures such as pits and furrows.

4. The proposed source of topsoil or other plant-growth medium should be identified for stockpiling and redistribution and the redistributed topsoil over spoil should have a minimum depth of 18 to 24 inches.

5. Species selected for revegetation should include the pre-mining grasses, forbs and browse species and should also include native and introduced species, sod and bunch-type grasses, nitrogen-fixing legumes, high and low growth forms, and deciduous and evergreen species.

6. Seeding methods should include drilling and broadcasting of seed with the addition of fertilizers and mulches (wood-fibre, or straw and hay anchored by 300 gal of asphalt/acre) which help to conserve soil moisture.

7. Planting has the best chance of success when made prior to the season of most dependable precipitation.

8. The seeding rate and mixture will vary with different sites and the method of planting, but in general poorer sites (south- and west-facing slopes) require more seed than more favourable slopes (north- and east-facing slopes).

In a discussion of the major vegetation types underlain by surface minable fuels in the western United States, it is pointed out that restoration procedures for desert and alpine zones have not received the attention given to intermediate zones, and known rehabilitation practices are largely lacking for these more extreme environments. The alpine zone with its short growing season, mainly shallow soils and native species that produce little seed, presents a difficult situation with respect to rapid and dependable means of rehabilitation. Alpine plants can be transplanted by sodding or by vegetation plugs, but the method is expensive and not suited to large areas.

1. COURTIN, G.M.

2. 1976

3. The application of processed organic wastes to acid mine tailings.

4. In: Proceedings of the Inaugural Meeting Canadian Land Reclamation Association, Crop Science Department, Ontario Agricultural College, University of Guelph, Guelph, Ontario, p 26-27

5. Original

6. a. Ontario; Canadian Taiga

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. Secondarily treated organic waste was applied to tailings of the International Nickel Company's Copper Cliff Mine beginning in 1973. Although the study is continuing, preliminary conclusions were reported in this paper. No serious heavy metal toxicity symptoms were noted in the plant trials. The lack of toxicity indicates that the organic matter is tying up heavy metals. This is a potential beneficial change separate from the improved texture and water-holding capacity that results from addition of organic matter to tailings. In addition, the nitrogen present in the treated organic waste is in a form favourable to plant growth and had a maximal effect as a fertilizer.

The efficacy of the tailings as a filter for bacteria associated with the use of sewage sludge is as yet undertermined.

1. CROCKER, R.L. and B.A. DICKSON

2. 1957

3. Soil development on the recessional moraines of the Herbert and Mendenhall Glaciers, south-eastern Alaska.

4. Journal of Ecology 45:169-185

5. Original

6. a. Alaska; South Coastal

   b. Southern Yukon; Overburden

7. This study documented a 200-year sequence of soil formation on the Herbert and Mendenhall recessional moraines, derived from quartz diorite. The corresponding vegetation development was from bare till and open pioneer stages to spruce forest. The pioneer stage, with fireweed (*Epilobium latifolium*), horsetail (*Equisetum variegatum*), lupine (*Lupinus nootkatensis*), shrubs and sporadic tree seedlings is replaced by a dense thicket of alder (*Alnus crispa* subsp. *sinuata*) and willow (*Salix* sp). This is gradually replaced by cottonwood (*Populus trichocarpa*) and spruce (*Picea sitchensis*) which grow up through the alder and willows. After 50 to 60 years, a cottonwood-spruce forest emerges with an understory of mature and declining shrubs. The cottonwoods are replaced by a spruce forest after 100 to 120 years.

Soil properties begin to change as the pioneer species *Epilobium* and *Equisetum* become established, often within 5 to 10 yr. These soil changes are:

1. A decline in bulk density as succession progresses;

2. An initial rapid decline in surface pH, followed by slower reductions in pH at greater soil depths;

3. Nitrogen accumulation occurs at a steady rate of about 4.0 g/m^2/yr (36 lb/acre/yr) in the mineral soil-forest floor from 10 to 60 years. By 60 years, 0.2 kg/m^2 (1800 lb/acre) of nitrogen have collected. The fall in rate of nitrogen accumulation at about 60 to 70 years very closely parallels the change from alder dominance to alder senescence;

4. Total organic carbon increases in the mineral soil-forest floor throughout the chronosequence with some reduction in rate of accumulation with age but not as pronounced as with total nitrogen;

5. Moisture in the surface soil increases with time.

1. CROCKER, R.L. and J. MAJOR

2. 1955

3. Soil development in relation to vegetation and surface age at Glacier Bay, Alaska.

4. Journal of Ecology 43:428-448

5. Original

6. a. Alaska; South Coastal

   b. Southern Yukon; Overburden

7. Changes in soil properties of extensive, recently deglaciated areas at Glacier Bay, Alaska are related to vegetation development from initial colonization of bare glacial till to the development of spruce-dominated forest.

Over time three major vegetation types can be recognized: the pioneer community, the willow-alder thicket, and the spruce forest. The pioneer plants all have mobile disseminules and there is great variability, initially, in the soil parent material. First to arrive are the mosses (*Rhacomitrium canescens* and *Rhacomitrium lanuginosum*), *Epilobium latifolium, Equisetum variegatum* and *Dryas drummondii*. This latter species is significant for its mat-forming habit. Three species of willow also establish at this time as prostrate forms.

In the second stage, the willows develop an erect habit and, along with alder, constitute the transition to the thicket stage, with alder becoming the thicket dominant. Sitka spruce (*Picea sitchensis*) supersedes the shrub stage, initially as pure stands, and later with two hemlocks (*Tsuga heterophylla* and *Tsuga mertensiana*).

Soil reaction (pH) falls rapidly with the establishment of vegetation and the type of plant markedly affects the rate of pH change. Alder possesses a remarkable acidifying effect; the uppermost soil horizons under alder were reduced in pH from 8.0 to 5.0 within 35 to 50 years. Calcium carbonate under alder also reduces from values of 5% to negligible in the first 35 to 50 years, a greater rate of change than with other species or in areas devoid of vegetation. Alder has an abundant leaf fall and its shrub habit is effective in trapping the leaf fall of other species such as *Salix* and *Populus*, the decomposition of which increases acidity. Within 40 to 50 years 5 to 6 kg/m^2 of above-surface organic residues 6 to 7 m deep accumulates under alder, with a pH range of 4.2 to 4.6. Organic carbon continuously increases,

Continued ...

Crocker, R.L. and J. Major. 1955. Continued

bulk density decreases, litter accumulates, pH declines rapidly at first and then does not change much after the alder thicket stage. Total nitrogen increases beneath *Dryas* and alder but decreases under spruce.

Dryas accumulates considerable quantities of nitrogen but is not as effective as alder. Accumulation of nitrogen in the *Dryas* mat was 1.04 to 1.33% of dry weight, approximately half as great as in litter beneath alder (2.08%). *Dryas, Shepherdia canadensis* and alder all have mycorrhizae capable of fixing nitrogen from the atmosphere. All three are capable of growing vigorously at low nitrogen levels characteristic of initial or glacial debris. Significant accretions of nitrogen can also occur without macroscopic vegetation and the relative presence of high nitrogen percent under remnants of algal crusts suggests that these microorganisms are also capable of nitrogen fixation or possibly surface adsorption of nitrogen.

1. CURRAN, H.J.B. and H.M. ETTER

2. 1974

3. Environmental design for northern road development.

4. Environmental Protection Service, Northwest Region. EPS 74-18.
   Unpublished report. Various paging

5. Original

6. a. Mackenzie District; Canadian Taiga, Canadian Tundra

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta
   Region; Roads

7. This report provides guidelines for route selection, environmental survey, alignment, design, construction and maintenance for northern road development, and Appendix A of the report is devoted to revegetation procedures. Two general aspects of revegetation are examined: 1) culture and management for establishing grasses and legumes; and 2) soil and site groups and recommended plants. Information for this appendix is primarily drawn from *A Vegetative Guide for Alaska,* U.S.D.A. Soil Conservation Service Publication M7-N-22612 (1972) and from recent studies in the Canadian and Alaskan Arctic and Subarctic.

The first section on culture and management is subdivided into several headings as follows:

1. Soils - The upper 12 inches should be loamy material able to hold at least 3/4 inch water; also soil should be sufficiently porous for root penetration and should be tillable for good seedbed preparation. Where topsoil has been removed, it may be necessary to replace it with 4 inches of loamy material before seeding.
2. Seedbed preparation - Seedbeds on level land require tilling and packing; a heel imprint should barely show on the surface. Incorporation of dead vegetation and organic matter by intensive cultivation is necessary for a satisfactory seedbed. On steep sloping land or construction sites where tillage machinery cannot be used, slopes should be prepared as well as possible and left roughened to increase catch of broadcast seed. A well prepared seedbed requires less seed and increases the success of planting.
3. Seed specifications - Use only northern strains of grasses and legumes. Germination and purity tests are necessary to determine correct seeding rate for each grass and legume variety. Legumes require scarification and inoculation with applicable nitrogen-fixing bacteria before seeding.

Continued ...

Curran, H.J.B. and H.M. Etter. 1974. Continued

4. Time of seeding - Early June seedings gives best results. Later seedings in summer can be made up to August 10 for grasses and legumes. For temporary cover to reduce erosion, annual ryegrass or cereal grain may be planted up to September 1, and then seeded to a perennial grass the following spring.
5. Seeding methods (four) - (1) Drill. For nearly level to sloping land, a grass drill is best, but slope and surface conditions will govern the method. Small seed is placed no more than 1/4 to 1/2 inch deep. Seed is packed during or after drilling. (2) Hydroseed. For steep slopes where drilling is not possible, hydroseeding is preferred. When seed, fertilizer and mulch are applied together, use not more than 100 to 150 lbs solid/100 gals water and it is cautioned that seed and fertilizer be well mixed in a tank at least 1/3 full of water before mulch is added. Once fertilizer is added, use within a few hours of mixing. Application of seed plus fertilizer first is best to ensure good seed contact with soil. The seed, fertilizer and mulch specifications are those given in *A Vegetative Guide for Alaska,* (1972). (3) Broadcast. Broadcast seeding requires double the rate of seed application recommended for drilling. (4) Sprigging. Sprigging (planting a shoot, root or sprout of a plant) and sodding (covering with sections of sod) are costly but may be preferable to seeding for critical situations.
6. Fertilization - This is necessary for good grass growth and should be repeated each year for best results. A general recommendation is 60-60-60 for NPK the first year with maintenance rates of 30-60-30 each year on construction sites or as indicated by soil tests. Other possible combinations are given in *A Vegetative Guide for Alaska.* For best results at least 1/2 nitrogen should be in nitrate form. Urea is not suggested because of its slow availability in northern soils.
7. Maintenance - Seedlings must be kept moist until grass reaches 1 to 2 inches height. Supplemental water should be added in prolonged drought periods, if possible, Critical sites especially may need moisture, reseeding, sodding and maintenance applications of mulch and fertilizer.
8. Mulching - The advantages of mulch for critical sites are moisture retention, soil protection from erosion, holding seed in place and keeping soil temperatures more constant. Mulch is applied uniformly by mechanical means or by hand so that some bare soil is visible through the mulch. Common types are: hay, small-grain straw, native bluejoint hay, straw-asphalt mix, wood fiber mulch, peat moss, gravel or jute matting. Use of grass seed straw or native bluejoint hay cut when hay is mature has the advantage of containing viable seed. Mulching is not necessary for favourable sites and should not be applied too early in spring as it may retard rate of soil warm up. Dark coloured binders used on north-facing slopes increase the surface temperature and promote early growth. Seeds coated with binder may fail to germinate or germinate slowly. To anchor mulch, press into soil with mulch anchor tool, tack with various binders or tie down cotton netting or wire mesh.

Continued ...

Curran, H.J.B. and H.M. Etter. 1974. Continued

9. Annual seedings - Annual ryegrass (*Lolium perenne*) provides quick growth for erosion control at seeding rates of 10 to 25 lb/acre or more planted before August 1. This should be followed by perennial species the following spring or should be planted in combination with perennial grass seed.
10. Native seeds - Native bluejoint (*Calamagrostis canadensis*) and arcticgrass (*Arctagrostis latifolia*) are excellent colonizers of disturbed areas in northern forest and tundra areas. Seed supplies are limited and they are slower growing than agronomic species.

Examples of species, mixes, varieties, and rates of seeding by drill are derived from *A Vegetative Guide for Alaska* for the five site types ranging from xeric to hydric.

1. CURTIS, W.R.
2. 1971
3. Terraces reduce runoff and erosion on surface-mine ventures.
4. Journal of Soil and Water Conservation 26:198-199
5. Original
6. a. Kentucky; Eastern Forest

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. Mechanical stabilization, involving terraces, can effectively control runoff and erosion on surface-mine ventures. This conclusion was reached after a two-year study in Kentucky in which four plots were compared. Two adjacent ridges with a control and experimental plot on each were selected, one primarily with soil of shale origin and the other with a high percentage of sandstone. Terraces were formed by a Rome bedding harrow followed by a shake roller so that the completed terraces were 7 to 8 ft apart and less than 8 inches high, constructed on a gradient of ± 1%.

In the predominantly shale area, peak flows on a terrace plot averaged 65% less than on the control plot, sediment yield averaged 52% less, and total runoff averaged 42% less. Comparable measurements on the primarily sandstone plots indicated that peak flow on the terraced plot was 65% less, sediment yield averaged 70% less, and total runoff averaged 6% less. Although shale weathers to smaller sizes than sandstone and its erosion potential is greater, the reduction in peak flow as a result of terracing was 65% for both watersheds. Average storm runoff duration was 1% higher on the terraced plot of each pair. When the growing and dormant seasons were assessed separately, a significant increase in runoff duration occurred on the terraced plots during the growing season and a slight reduction in the dormant season.

The plots were hydroseeded with a mixture of annual ryegrass, sweet clover, Kentucky-31 fescue and black locust. Based on visual comparison, a better vegetation cover grew on the terraced plots, a fact attributed to the effective seedbed preparation and moisture conservation.

1. DABBS, D.L.

2. 1974

3. Rationale and problems in the use of native pioneer species in land reclamation.

4. In: D. Hocking and W.R. McDonald, Editors, Proceedings of a Workshop on Reclamation of Disturbed Lands in Alberta, Northern Forest Research Centre, Edmonton, Information Report NOR-X-116, p82-87.

5. Original

6. a. Mackenzie District; Canadian Tundra, Canadian Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon Coast; Roads

7. A distinction is made between revegetation, a quick provision of plant cover for erosion control, and reclamation, the restoration of a damaged ecosystem to a primary successional state using the same species that would naturally invade over time. Attention is given in this paper to reclamation based on the experience of developing such a program within Canadian Arctic Gas Study Limited.

For this research plots were established at four northern locations to determine which species and varieties would establish and grow in the subarctic and arctic regions. The plot experiments established that certain commercial grass species can survive and provide good cover for 3 or 4 years but their long-term capability is not yet known. Two native pioneer grasses, *Calamagrostis canadensis* and *Arctagrostis latifolia*, were slow to establish at first but by the third year their cover and biomass equalled or exceeded most of the commercial grasses. Their annual production was 2 to 8 times that of the two commercial species that did not winterkill, Arctared creeping red fescue and Nugget Kentucky bluegrass.

The problems of using native species are: (1) to obtain sufficient seed stock for field multiplication; and (2) to raise on an agricultural scale species adapted to disturbed northern niches. To cultivate and increase the seed of the two mentioned native species requires knowledge of their flowering and seedhead production at lower latitudes, the cultural practices necessary to maximize seed production, and the ecotypic varieties best suited to the objective, in this case pipeline right-of-way revegetation.

Continued ...

Dabbs, D.L. 1974. Continued

The scope of the research topics under investigation at the time that this paper was presented provide some measure of the complexity of the task. Study of species performance was underway to determine the effect of interspecific competition of species, and to compare root and shoot production of native and agronomic species. Ecotypic variation studies were also underway from various northern locations between 60° and 70° N latitude to identify traits and varieties desirable for revegetation purposes. Seed increase plots will be necessary to determine the influence of fertilizer and irrigation treatments on flowering and seed production.

Future research must determine: (1) the level of each factor alone or in combination that is most conducive to flower production; (2) the differences in flowering requirement of strains from other latitudes; (3) ways of shortening the time for seed production; and (4) traits which will maximize seed production. The author indicated that the practical use of native species has still to overcome many obstacles.

1. DABBS, D.L.

2. 1975

3. Revegetation

4. In: Canadian Gas Arctic Study Limited, The impact of a pipeline and Mackenzie corridor development on the living environment. Testimony presented to the Mackenzie Valley Pipeline Inquiry. p. 7-18

5. Original

6. a. Mackenzie District; Canadian Tundra, Canadian Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon Coast; Roads

7. Three major avenues of research were utilized for vegetation studies conducted for Canadian Arctic Gas Study Ltd. First, a vegetation survey and classification were made of the proposed route, to define it in ecologically meaningful units. Secondly, revegetation trials were established at several locations along the route, plus additional evaluation of species performance. Lastly, environmental monitoring was planned over several years to establish the natural conditions of drainage, soil and vegetation prior to any construction.

The primary objective of the revegetation program is to provide initial erosion control cover for stabilization and to aid natural plant succession processes for the re-establishment of a permanent, stable natural plant cover.

It may be necessary in tundra regions to supplement the seeding and fertilization with other techniques such as planting of shrub cuttings, erosion control mats, and stripping and replacement of tundra cover to achieve the degree of revegetation required. Additional seeding and fertilization may also be required but is expected to be limited to small sections.

Research conducted by Canadian Arctic Gas and by Hernandez (1973) has shown that the use of agronomic varieties of grasses does not constitute a threat to native plant communities. However, species proposed are native or long-adapted species, and all belong to genera which are a natural part of northern ecosystems. Creeping red fescue, reed canary grass and slender wheatgrass are native to boreal regions of Canada. The commercial varieties are genetic strains derived from existing native populations. Kentucky bluegrass, meadow foxtail and timothy are typical of cool temperate regions and red top is common in western Canada.

Continued ...

Dabbs, D.L. 1975. Continued

Revegetation research has also demonstrated the value of two unlicensed varieties, Arctared creeping red fescue and Engmo timothy, for use in arctic regions. These have since been released by Agriculture Canada specifically for arctic revegetation.

Arctic Gas has arranged with a seed broker for assistance in seed multiplication contracts for large quantities of northern seed varieties not commercially available. A long lead time is required to build the necessary seed supply for a major construction undertaking. The applicant expects to revegetate the pipeline right-of-way successfully, although problems are expected in some areas, particularly with the unpredictability of climatic variation. A surveillance program is planned to identify these areas and to take action against erosion problems.

A potential impact of revegetation programs is the disturbance of wildlife due to seeding activity. It is suggested that aerial winter seeding would avoid critical times of year for waterfowl and mammals. Helicopter seeding in northern areas would not commence before June 20, which is a week or more after the last known date of calving of the Porcupine caribou herd.

1. DABBS, D.L.

2. 1976

3. Revegetating the North.

4. Agrologist 5(4):28-30

5. Original

6. a. Mackenzie District; Canadian Tundra, Canadian Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon Coast; Roads

7. The author was responsible for development of plant ecology and revegetation projects for the proposed Mackenzie Valley gas pipeline project. A major revegetation research program was initiated in 1971 at the Sans Sault Rapids, Northwest Territories, test station where three experimental pipelines were built. The program was designed to select grass varieties that would provide cover for erosion control and yet survive the long winter, short growing season, 24-hour day length in summer and permafrost in cold nutrient-deficient soils. In these tests, the plots were broadcast seeded to simulate aerial seeding and no seed-bed preparation was made. Fertilizer was applied and the initial results showed rapid growth of the seeded grasses. However, after several seasons many of the southern grass varieties were winter killed, leaving 8 to 10 varieties suitable for revegetation in the mid and upper Mackenzie Valley.

In other projects, helicopter seeding of abandoned drill sites in the Mackenzie Delta helped to develop procedures, seed mixes and rates of applications for large, heterogeneous disturbances in northern areas. In this program, forage grasses were intended as a temporary treatment for erosion control with the long-term stability dependent on regrowth of native species. Encouragement of native plant re-establishment is dependent on several factors: (1) careful regulation of seeding rates for forage grasses and fertilizer applications to create a cover sufficient for erosion control and yet not so dense as to exlude the invasion of native species; (2) native species are incorporated in the seed mix, relying particularly on two of the most prominent native grasses (*Calamagrostis canadensis* and *Arctagrostis latifolia*) for the forested and northern regions respectively.

A northern adapted species' seed source is being developed in the Mackenzie Delta. The possibility of using native woody shrub stem cuttings (willow and alder) at river crossings, and mats and mulches for erosion control of steep slopes is being examined. Topsoil

Continued ...

Dabbs, D.L. 1976. Continued

salvage for borrow pit restoration and the mechanical stripping and replacement of tundra vegetation, possibly as a supplement to seeding and fertilization are further methods for control of erosion.

An important part of the revegetation program has been a complete survey of the landscape of the entire length of the projected pipeline and this study has provided a basis for impact assessment and a data base for revegetation and planning. As many of the chosen forage grass varieties, including Arctared creeping red fescue, Nugget Kentucky bluegrass and Engmo timothy, have limited supply, seed multiplication agreements were made with growers in various locations in Canada and the United States with a delivery schedule contingent on the construction plans of the project.

The author stressed that a physically stable condition with proper drainage and erosion control must exist before attempting to revegetate. This is more of a problem in permafrost regions where removal of the insulative organic mat can initiate greater thaw depth in the summer months causing an increased potential for erosion. The buildup of dead organic material from a stand of vegetation is significant in restoring the pre-construction thermal regime which is important for the stability of permafrost terrain.

1. DABBS, D.L., W. FRIESEN and S. MITCHELL

2. 1974

3. Pipeline revegetation.

4. Prepared by Northern Engineering Services Company Limited for Canadian Arctic Gas Study Limited, Biological Report Series, Volume Two. 67 p

5. Original

6. a. Mackenzie District; Canadian Tundra, Canadian Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon Coast; Roads

7. This is an account of first year and second year results of revegetation research at the pipeline test facility at Sans Sault Rapids (65 40 N, 128 49 W) in the Mackenzie River valley.

The objective was to test the suitability of 23 species, mostly grasses, for use in revegetating disturbed land surfaces in the northern boreal forest. The tested species were evaluated on the basis of: rate of growth; ground covered by shoot : biomass production; rate and depth of rooting; litter accumulation; winter survival; nutrient requirement for establishment and continued growth; insulative value and effect on soil energy budget.

Other parts of the study included an evaluation of hand planting shrub cuttings on side slopes and approaches to rivers, the relationships between small mammals and newly established grass cover, and the potential of stripping and replacing the surface tundra mat as an alternative to seeding. The latter study was conducted in the northern Yukon near the coast.

The best grasses for revegetation in the Sans Sault Rapids area were: Boreal creeping red fescue, common Kentucky bluegrass, common meadow foxtail, Frontier reed canary grass, Climax timothy, Revenue slender wheatgrass and meadow fescue. For the Sans Sault area, a recommended seed mix to be applied by aerial broadcast seeding would include:

Boreal creeping red fescue	@	10-15 lb/ac
Common Kentucky bluegrass	@	10-13 lb/ac
Common meadow foxtail	@	10-13 lb/ac
Frontier reed canary grass	@	10-15 lb/ac

An additional 5 lb/ac Climax timothy or meadow fescue could be used to add diversity to the mix. Timothy could replace the meadow foxtail in the mix if the latter is not available. On dryer, well drained soils, it is necessary to add 5 to 10 lb/ac Revenue slender wheatgrass. In this case, an equal amount of reed canary grass could be deleted.

Continued ...

Dabbs, D.L., W. Friesen and S. Mitchell. 1974. Continued

In 1972, plantings of alsike clover and alfalfa did not perform well and are, therefore, not recommended for the latitude of Sans Sault. Undoubtedly these legumes would prove beneficial in the seed mix in more southerly locations.

The authors recommend that stripping or sodding could be effectively used in two major areas:

(1) the wet sedge tundra lowlands where there would be an abundance of rhizomes in the sod that would continue to grow. These areas would be difficult to establish grass from seed due to the wetness of the area;

(2) the tussock cottongrass region in the rolling uplands of the Arctic plateau. The tussocks of cottongrass quickly re-establish.

The slope stabilization study involved planting shrub cuttings on a seismic line, on side slopes and on roadways in the fall of 1971. As of August, 1972, survival of shrubs on the seismic line was as follows; *Salix alaxensis* 94%; *Salix arbusculoides* 83%; *Salix planifolia* 22%; *Alnus incana* 60%; *Alnus crispa* 100%; *Cornus stolonifera* 0%; *Betula papyrifera* 0%.

The total area planted was 315 m^2 at a density of 10.3 cuttings per square metre. This planting program required 52 man hours. These figures convert to 1650 man hr/hectare or 660 man hr/acre. With more experience and improved efficiency, plus a lower density, this could be reduced to 1500 man hr/hectare or about 600 man hr/acre. The authors concluded that the planting of willow and alder stem cuttings was an effective method to control erosion on sideslopes. Some slopes may also require erosion control mats.

The results of two season's growth of grasses on a simulated pipeline right-of-way in the northern boreal forest showed that a binding plant cover can be successfully established and maintained. However, the seeding of grasses was not considered to be a long term restoration measure. It is much more important that a diverse, stable natural plant community quickly establish on disturbed areas. In the Sans Sault Rapids area the most abundant natural invaders of disturbed areas were *Arctagrostis latifolia, Epilobium angustifolium, Equisetum arvense, Senecio congestus, Carex aquatilis* and various mosses and liverworts. The mosses and liverworts quickly established under the seeded grasses over the backfill mound. Vascular plants were slower to invade except in areas that collect water; these areas were dominated by *Carex aquatilis.*

Fertilizers are required to establish and maintain growth of the recommended grass varieties. For a pipeline backfill mound the authors recommended 75 kg/ha nitrogen plus 100 kg/ha of both phosphorous and potassium, plus additional applications in the second and third growing seasons.

The authors concluded that small mammals occurring in "average densities" would not cause large scale destruction of the reseeded vegetative cover.

1. DAFT, M.J., E. HACSKAYLO and T.H. NICOLSON

2. 1975

3. Arbuscular mycorrhizas in plants colonizing coal spoils in Scotland and Pennsylvania.

4. In: F.E. Sanders, B. Mosse and P.B. Tinker, Editors, Endomycorrhizas, Proceedings of a Symposium held at the University of Leeds, Academic Press, London, p 561-580.

5. Original

6. a. Pennsylvania, Scotland; Eastern Forest, British Forest

   b. Southwestern Mackenzie, Southern Yukon; overburden

7. Preliminary research suggests that arbuscular mycorrhizas play a similar function in herbaceous plants that ectotrophic mycorrhizas have for trees colonizing coal spoil. Endomycorrhizas found on plants colonizing six coal waste sites in Pennsylvania and Fife, Scotland were compared. All of the plants examined, with the exception of a *Carex* sp and *Reseda luteola*, were infected with arbuscular mycorrhizas. Number of species colonizing spoil varied as did the levels of infection. Herbaceous plants and grasses were the main colonizers in Scotland during natural revegetation, including such species as *Agrostis tenuis*, *Dactylis glomerata* and *Festuca ovina* with others. Species lists for both locations are given with the type of endophyte identified and the average level of infection.

The endophyte flora in Pennsylvania proved more diverse than on the Scottish tips. In Pennsylvanian spoils, *Gigaspora gigantea* and a number of chlamydosporic *Glomus* spp. were most frequent. In Scottish materials, two *Glomus* spp. were the most abundant endophytes. Also present in Scottish materials were *Gigaspora calospora* and the endophyte with narrow hyphae which was more restricted to pioneer colonizing plants. These were present but much less frequent in Pennsylvanian materials.

The narrow hyphae endophyte was often present on pioneer colonizing species. This endophyte has been found abundantly in high altitude soils of New Zealand and could stimulate plant growth under very low phosphate conditions and for this reason its presence on pioneer plants on coal tips could be of considerable significance.

Continued ...

Daft, M.J., E. Hacskaylo and T.H. Nicolson. 1975. Continued

A particular search was also made for mycorrhizal and nodulated plants, which are thought to fix atmospheric nitrogen more efficiently than nodulated plants only. In Pennsylvania, five nodulated and mycorrhizal species were found growing in spoils. Such dually infected plants offer added advantages as colonizers, one of which is that the efficiency of the nodules is increased. A surprising lack of nodulated plants colonizing Scottish sites was reported.

1. DEAN, K.C. and R. HAVENS

2. 1973

3. Comparative costs and methods for stabilization of tailings.

4. In: C.L. Aplin and G.O. Argall, Jr., Editors, Tailings Disposal Today, Proceedings 1st International Tailings Symposium, Miller Freeman, San Francisco, p 450-476

5. Original

6. a. Utah; Great Basin

   b. Yukon and Northwest Territories; Tailings

7. Several milling companies alone or in cooperation with United States Bureau of Mines have applied various stabilization techniques to differing types of wastes in different environments with the objective of achieving effective low-cost stabilization requiring minimal maintenance. The fine wastes derived from the mining and milling industry represent the most difficult materials to stabilize. The principal methods for stabilization include physical (covering the tailings with soil or other restraining materials), chemical (application of some material to interact with fine-sized minerals to form a crust) and vegetative (the growth of plants on tailings). The vegetative procedure is preferred because it improves the aesthetics of the area while also achieving stabilization. Rock and soil obtained from nearby areas are useful in physical stabilization which has the advantage that vegetation can also grow in the soil. In addition to locally available soils and country rock, slag has been used to stabilize inactive tailing ponds but this has the disadvantage of being an unfavourable habitat for vegetation. Other physical methods of stabilization include the use of bark covering and the harrowing of straw into the top few inches of tailings.

Chemical stabilization is achieved by reacting a reagent with mineral waste to form a layer or cover which inhibits wind and water erosion. These are not as permanent as vegetation for stabilization but can be used on sites unsuited to vegetation growth because of harsh climatic conditions or the presence of toxic elements in the tailings.

Listed below are some of the more effective chemicals from over 70 tested. Optimum conditions and effective rates of application have not been determined and testing continues. They are listed in order of effectiveness based on cost in cents to stabilize one square yard.

1. Coherex (trade name) a resinous adhesive, furnished wind-resistant tailings surfaces when applied in quantities costing as little as $0.01 per square yard, but resistance to water jet testing was not achieved until reagent costing about $0.10 per square yard was applied.

Continued ...

Dean, K.C. and R. Havens. 1973. Continued

2. Calcium, ammonium, and sodium lignosulfonates, as well as redwood bark extracts, were all effective surface stabilizers at costs of about $0.02 per square yard.

3. Cement and milk of lime additives were effective in stabilizing surfaces when applied in amounts costing $0.03 per square yard.

4. Paracol S 1461 (a blend of wax and resin) and Paracol TC 1842 (a resin emulsion) were effective as stabilizers in quantities ranging in cost from $0.04 to $0.10 per square yard on various tailings samples tested.

5. Potassium silicates having SiO_2-K_2O ratios of 2.5 were effective stabilizers when applied at a rate of $0.07 to $0.15 per square yard.

6. A cationic neoprene emulsion and Rezosol, an organic polymer, effectively stabilized tailings at costs approximating $0.08 per square yard.

7. Sodium silicate applied in quantities of 4.5 pounds per square yard and at a cost of $0.11 per square yard was an effective stabilizer. Calcium chloride was an effective additive to the sodium silicate, whereas ferrous sulfate was not. Addition of 6 percent by weight of $CaCl_2$ permitted reduction of the cost of sodium silicate used from $0.11 to $0.02 per square yard.

The U.S. Bureau of Mines developed a chemical-vegetative procedure where small amounts of chemicals are applied to newly planted tailings to retain moisture, prevent sandblasting, promote germination and minimize wilting by creating a dark, heat-absorbing and non-reflective surface. A seed mix of grass, legumes and grains is made with fertilizer and is planted and watered before chemical stabilization is applied, preferably in the fall. This chemical-vegetative procedure has been effectively used on copper, lead-zinc, uranium and clay tailings under different climatic conditions in Colorado, Michigan, Missouri, Nevada and Washington states.

Research is also in progress to aid vegetation growth on problem tailings by making synthetic soils from tailings to which is added sewage sludge or refuse compost. Pelletizing the tailings provided a better root environment and better soil aeration. The pellets were 92.4% tailings, 6.6% sewage sludge and 1% chemical binder (either Coherex or Paracol TC 1842, both of which are resinous compounds). In these tests the sewage sludge layers were buried at depths of 3, 7, 11 and 15 inches. The results from these tests indicated that the root system of all plants was principally located in the pelletized portion of the tailings.

1. DEAN, K.C. and R. HAVENS

2. 1973

3. Methods and costs for stabilizing tailings ponds.

4. Mining Congress Journal 59(12):41-46

5. Original

6. a. Utah; Great Basin

   b. Yukon and Northwest Territories; Tailings

7. The U.S. Bureau of Mines, at the Salt Lake City Metallurgy Research Center, has developed a chemical-vegetative procedure that involves the application of a small amount of chemicals to newly planted tailings. This procedure minimizes sand blasting of plants, retains moisture in the tailings, promotes germination and minimizes wilting.

Early fertilization tests showed that all tailings required nitrogen and phosphorus additions, but that nitrogen in quantities of more than 45 lb per acre seriously hampered legume seed germination. Hence, most tailings were fertilized with 30 and 75 lb per acre, respectively, of nitrogen and P_2O_5. A few tailings required potassium, in which case up to 40 lb of potassium per acre were added.

All seeds used in planting were selected for compatibility with the particular climatic environment in which the tailings were located. A suitable grain was added to the seed mixture to provide early growth for assisting the chemical in stabilizing the surface. The chemical, preferably thus far a resinous adhesive type, was applied to the moistened tailings in amounts costing 1 cent or less per square yard. This stabilization procedure generally is best applied in the fall of the year so as to achieve some growth before the onset of winter, thus allowing the root system to develop under a cover of snow and with good moisture conditions. The chemical-vegetative procedure has been effectively applied to copper, lead-zinc, uranium and clay tailings under widely different climatic conditions existing in Colorado, Michigan, Missouri, Nevada and Washington.

Stabilization costs for tailings consisting of 80% pond and 20% dike are summarized by the author in the following table. These costs would need to be revised upwards for acidic tailings requiring limestone. In general, costs for reclaiming sloping dike areas are about 25% greater than costs for flat pond areas.

Continued ...

Dean, K.C. and R. Havens. 1973. Continued

TYPE OF STABILIZATION	EFFECTIVENESS	APPROXIMATE COST/ACRE, DOLLARS
Physical		
Water sprinkling	Fair	-
Slag (9-in. depth)		
By pumping	Good	$350- 450
By trucking	Good	950-1,050
Straw harrowing	Fair	40- 75
Bark covering	Good	900-1,000
Country gravel and soil		
4-in. depth	Excellent	250- 600
12-in. depth	Excellent	700-1,700
Chemical		
Elastomeric polymer	Good	300- 750
Lignosulfonate	Good	250- 600
Vegetative		
4-in. soil cover and vegetation[1]	Excellent	300- 650
12-in. cover and vegetation	Excellent	750-1,750
Hydroseeding	Excellent	200- 450
Matting[2]	Excellent	600- 750
Chemical-vegetative	Excellent	100- 250

[1] Generally used on pond area rather than on dikes. Also, not as effective as 12-in. soil cover when tailings are excessively acidic or saline.

[2] Based on placing 3-ft wide matting at 3-ft intervals over the seeded area.

The chemical-vegetative procedure appears to be the most economical procedure for establishing vegetation on tailings and wherever applicable should be a preferred method. Where prevention of blowing sands is the major problem in achieving stabilization, both the chemical-vegetative and hydroseeding methods appear to be economically preferable to the matting or soil-covering procedures. However, for difficult areas, these latter methods may be mandatory.

Continued ...

Dean, K.C. and R. Havens. 1973. Continued

Practically all mill tailings contain deleterious inorganic salts, lack organic components and essential nutrients, and do not have the physical nature required for sustaining vegetative growth. For average tailings, these conditions can be overcome in time by fertilization, gradual buildup of organic and microbial populations by encouraging plant growth, and use of chemicals for binding of the surface to prevent blowing of loose sands that cut off or bury established vegetation.

One of the major problems with growing plants on tailings is the lack of organic matter and accompanying microbial populations. Efforts have been made to offset this problem by combining tailings with sewage sludge or municipal compost. Other tests have also been conducted to improve soil aeration and the root environment by pelletizing the tailings. Cost comparisons for these auxiliary stabilization methods are as follows:

TYPE OF STABILIZATION	EFFECTIVENESS	APPROXIMATE COST/ACRE DOLLARS
Buried sludge layers	Excellent	$405- 810
Pellet cover (1 - 1/2 in.)	Excellent	330- 660
Combined buried sludge plus pellet cover	Excellent	735-1,470

The buried sludge layer and pelletized cover methods are still unproven in the field, but if the calculated cost range of $735 to $1,470/acre is approximately correct for these methods then this procedure is comparable in cost to that using a 12 inch soil cover and vegetation. The authors recommend tests to evaluate the relative effectiveness of both procedures (combined buried sludge and pellet cover versus soil cover and vegetation) for obtaining vegetation on adverse tailings sites.

1. DICK, J.H.

2. 1974

3. Criteria for land reclamation standards in British Columbia.

4. In: Land reclamation short course, sponsored by Faculty of Forestry, University of British Columbia, Centre for Continuing Education, University of British Columbia, and Mining Association of British Columbia. Various paging

5. Original

6. a. British Columbia; Coastal, Interior, Rocky Mountain

   b. Alpine, Southern Yukon, Southwestern Mackenzie; Overburden

7. The great environmental diversity present in British Columbia means that province-wide standards for land reclamation after mining will be unworkable. Specific standards will have to be set for each "biogeoclimatic zone" of the province and these standards may be further refined for each mine site.

Standards in the United States have generally been based either on slope limitations, vegetative cover or both. It is felt this approach is too simplistic to be applied without modification because of the complex nature of soils, climate and topography in British Columbia. The degree of natural ground cover, which is used as a criterion in the West Virginia reclamation regulations, for example, would be difficult to apply in British Columbia because it would be so dependent on variations in climate and topography.

Criteria on which reclamation standards should be based in British Columbia are: 1) reclamation land use objectives; 2) surface drainage control; 3) ground cover, in which the degree of vegetation cover that existed on a site prior to mining or contiguous to a mine site is the guide; 4) ecological stability using native or naturalized species; and 5) plant vigour as measured by the growth of individual plants, increase in ground cover or production of viable seeds.

The first two criteria would need to be subjectively assessed; the last three can be measured using standard range and forest assessment methods.

1. DICK, J.H.

2. 1974

3. Selection and propagation of woody plant species for reclamation in British Columbia.

4. In: Land reclamation short course, sponsored by Faculty of Forestry, University of British Columbia, Centre for Continuing Education, University of British Columbia, and Mining Association of British Columbia. Various paging.

5. Original

6. a. British Columbia; Coastal, Interior, Rocky Mountain

   b. Alpine, Southern Yukon, Southwestern Mackenzie; Overburden

7. Surface mine revegetation has utilized grass and legume seed mixtures and coniferous seedlings primarily. The author feels that these are important, but in this paper emphasizes the significance of broadleaf trees and shrubs which have hitherto received little attention.

Trees and shrubs used in conjunction with grasses and legumes have several valuable characteristics:

(1) Food and cover for animals. Half the mammals and almost 60% of the birds indigenous to North America are associated with woody vegetation where shrubs and broadleaved trees are important components;

(2) Aesthetics. Trees and shrubs can do much to ameliorate a post-mining landscape, particularly a uniform series of slopes and benches which may be unaesthetic;

(3) Erosion control. Mixtures of woody and herbaceous species achieve greater ground cover than pure stands, and trees and shrubs are more effective in preventing wind erosion. Their deeper rooting provides valuable mechanical support for the soil;

(4) Nutrient cycling. Pioneer vegetation, of which shrubs are a major component, have an important function as a reservoir for nutrients. Several shrubs, such as alder, buffalo berry and silverberry, also fix nigrogen;

(5) Native species. Material for the vegetative propagation of native trees and shrubs can be collected relatively easily.

Selection criteria for species should take account of the following requirements. Reproduction material for reclamation purposes should be collected from vegetation that is established on the oldest disturbed

Continued ...

Dick, J.H. 1974. Continued

sites within ecological or altitudinal zones representative of the mine site. As a general rule, seedlings should be planted within ± 500 feet of the elevation from which the reproductive material (seeds or cuttings) was collected. The basis for selection of individual species should be, in order of importance: 1) native or naturalized species; 2) easily reproducable in large quantities; 3) ability to regenerate on and stabilize disturbed land; 4) nitrogen-fixing capability; 5) high value for a specific land-use objective; 6) proven effective in reclamation work elsewhere.

Details are given for the specifications of a small nursery for the production of easily propagated species to serve the needs of mining companies.

Seed demand for most reclamation programs will be small and can be collected by hand-stripping from bushes and felled trees. Seed can be extracted from dry fruit by crushing between bricks and from pulpy fruits and berries by macerating in water. Conifer seeds require handling by a seed dealer. Seed should then be air dried for a couple of days and then refrigerated until used.

Seed of most temperate species is dormant at ripening time in late summer or early fall, either as embryo dormancy which requires chemical changes before there can be any germination of the seeds or else as seed coat dormancy which requires weathering, and treatment, hot water or mechanical scarification to break dormancy. Embryo dormancy can be broken by planting outside in autumn for dormancy to be broken "naturally" or by soaking seed in water and refrigerating for four to six weeks.

Several methods of vegetative stem cuttings are described - hardwood cuttings (dormant shoots), softwood cuttings (current season's growth), and evergreen cuttings using common juniper or broadleaved evergreens such as *Arctostaphylos uva-ursi*.

Root cuttings, sections of young roots 2 to 3 inches long and about a pencil's thickness, can also be made. These are planted either vertically or horizontally. If planted vertically, care is needed to plant the end nearest the parent plant uppermost.

The following genera of potential use in the north grow on mine spoil in British Columbia. Information is given on range, habit, uses and method of propagation, but only the recommended method of propagation is noted here.

Alnus rubra *Alnus sinuata* *Alnus tenuifolia*	- From seed either fall sown or stratified for 60-90 days at 41° F. The shrub species may strike from root cuttings.
Amelanchier alnifolia	- Root cuttings taken and planted in spring.
Arctostaphylos uva-ursi	- Evergreen cuttings. Seed after acid treatment for 2-3 hours and stratification for 60 days @ 41°F.

Dick, J.H. 1974. Continued

Artemisia frigida - Stem cuttings, root cuttings and plant division.

Betula papyrifera - Fall sowing or stratification for 4-6 weeks @ 40° F.

Cornus stolonifera - Fall sowing. Stratify 3-4 months at 41° F. Root and hardwood cuttings.

Populus tremuloides - Root cuttings. Does not strike from stem cuttings.

Populus trichocarpa
Populus balsamifera - Very easy from hardwood cuttings.

Rosa spp - Fall sowing or stratify 60-120 days @ 40° F. Acid treatment may help. Softwood cuttings and hardwood cuttings.

Salix spp - Very easy from root, hardwood or softwood cuttings.

Shepherdia canadensis - Seed stratified 60-90 days @ 41° F. Root cuttings.

Symphoricarpos albus - Very difficult from seed. Root, hardwood and softwood cuttings.

1. DICK, J.H. and J.V. THIRGOOD
2. 1975
3. Development of land reclamation in British Columbia.
4. In: M.K. Wali, Editor, Practices and problems of land reclamation in western North America, University of North Dakota Press, Grand Forks, North Dakota, p. 65-78
5. Original
6. a. British Columbia; Coastal, Interior, Rocky Mountain

   b. Alpine, Southern Yukon, Southwestern Mackenzie; Overburden

7. The Mines Regulation Act and Coal Mines Regulation Act (1969) of British Columbia established general policy and regulations for mine reclamation. By these statutes, it is industry's responsibility to develop reclamation technology and procedures. The government exercises an inspection function. This is a system that the authors feel has failed to achieve satisfactory standards.

Reclamation has been shown to be biologically possible in almost every region of British Columbia. However, general shortcomings and inadequacies in reclamation efforts remain, such as:

1. The failure to include reclamation and land use objectives in operational planning; more preplanning of excavation and dumping procedures is required so as to produce nearly stable slopes, bury harmful or problem waste materials and provide surface soils that can support vegetation.

2. The failure to recognize reclamation needs as a constraint on mining practice. Reclamation land-use objectives will determine the final configuration of disturbed land and the selection of species.

3. The failure to recognize site factors as constraints to revegetation.

4. Poor species selection. More attention is needed on selection of grass and legume species adapted to site conditions, use of native species and patterns of local ecological succession.

5. Effective reclamation can be achieved by a combination of methods; there has been a tendency to favour one technique, such as aerial seeding or hydro mulching.

6. A lack of emphasis on results and assessment.

Three future needs in reclamation for British Columbia are defined: 1) greater cooperation between government agencies and industry to develop land use objectives for mined lands; 2) greater direction from government

Continued ...

Dick, J.H. and J.V. Thirgood. 1975. Continued

departments for environmentally compatible methods of mining and exploration, long-term reclamation research projects (species trials and native plant propagation particularly) and the establishment of sound reclamation standards and guidelines; and 3) better understanding by the mining industry of the relationships between environmental diversity and the development of reclamation technology, and more cooperation and communication between companies working in comparable geographical zones.

1. DONAVAN, R.P., R.M. FELDER and H.H. ROGERS

2. 1976

3. Vegetative stabilization of mineral waste heaps

4. U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Environmental Protection Technology Series PB-252 176, Research Triangle Park, North Carolina 27711. 305 p

5. Original

6. a. United States

   b. Yukon and Northwest Territories; Tailings

7. This report reviews the use of vegetation as a control method for fugitive dust emissions from man-made mineral waste heaps. The review covers the United States, excluding Alaska, and emphasis is on methods of controlling dust emissions from waste heaps. There is a detailed review of case histories of both successful and unsuccessful revegetation. A detailed appendix provides a catalogue of species that have been tried in mineral spoil and tailing revegetation programs, with notes that summarize the experiences recorded for each species.

Information was summarized according to the main United States sources of mineral ore wastes, with separate state-of-the-art reviews for: refuse from deep coal mines, surface coal mining spoils, coal mine refuse banks, coal mine slurry ponds, asbestos wastes, copper tailings, iron ore tailings, lead and zinc tailings, uranium ore tailings, phosphate mining wastes, pulverized fuel ash, spent oil shale, and sand and gravel pits.

The authors stress the importance of plant succession and indicate that the initial mission with regard to any waste pile is to get something to grow. As time goes on, the pioneer species will improve conditions so that other species will become established.

The importance of planning is strongly emphasized. In particular, proper stockpiling of topsoil and overburden in any mining operation will allow the eventual reclamation to be done at minimal cost and effort.

In spite of the lengthy and intensive investigations of vegetative stabilization of mineral waste heaps that have been and are being carried out by United States Government, university and industrial researchers, the problem is still too complex to permit the formulation of guaranteed revegetation procedures. In practice each new candidate site for vegetative cover must be treated as a unique problem; trial and error

Continued

Donavan, R.P., R.M. Felder and H.H. Rogers. 1976. Continued

experimentation on test plots must precede any large scale revegetation effort, using previous experiences as general guidelines to formulate the test program.

Given enough time and resources, any mineral waste heap in the United States could be covered with vegetation; the problem is to establish a cover at a cost compatible with the value of the land before and after the reclamation. It might appear to be folly to dig up a land area for a net gain of $500/acre, if the cost of returning the land to its previous state is $5000/acre. If the $5000/acre investment can enhance the value of the land - make it worth more after mining and reclamation than before - then the high post-mining costs of the land transformation may be justified. In short, the optimum strategy to pursue in any given vegetative stabilization task, including whether to even consider or attempt a vegetative solution, depends strongly upon economic factors.

In this state-of-the-art review of vegetative stabilization of mineral waste heaps, horticultural techniques are described which are generally applicable, but horticulture is as much an art as it is a science when directed at a specific reclamation problem. The report outlines some of the recent horticultural innovations including the use of surface binding materials which provide temporary terrain stability while vegetation is being established.

This study focussed mainly on an assessment of the effectiveness of vegetative cover for suppressing the emission of suspended particulates. No measurements of the effectiveness of vegetation in reducing the emission of suspended particulates now exist. All evaluations of vegetative cover are expressed in either qualitative agricultural terms - "good cover, grows well" - or in semiquantitative terms - "50 percent survival, 20 percent coverage." What is really needed is a direct measure of the suppression of emissions of suspended particulates. Some species may be better than others in controlling emissions.

1. DOWN, C.G.

2. 1974

3. The relationship between colliery-waste particle sizes and plant growth.

4. Environmental Conservation 1:281-284

5. Original

6. a. England; British Forest

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Many factors may account for the relationship between spoil age and plant colonization. In this article, samples of spoil particles from 12-year-old colliery spoil from a Somerset coalfield in England were separated into seven size-fractions and *Lolium perenne* (perennial ryegrass) seeds were sown on each spoil surface. The size range of spoil was from more than 4000µ to less than 125µ and the growth period was 30 days.

Results indicated that germination percentages after six days increased with decreasing spoil particle-size. The same was also true of dry-weight and shoot : root ratio which were inversely proportional to particle size. After 30 days there was no distinction between seedling dry-weights on the different particle sizes. On the largest size fractions, it proved difficult to keep plants alive because of the poor water-holding capacity.

An ideal mineral waste would possess a mixture of small and large particles. The large particles would provide stability while the small particles would provide water-holding capacity.

1. DOYLE, P., W.K. FLETCHER and V.C. BRINK

2. 1973

3. Trace element content of soils and plants from the Selwyn Mountains, Yukon and Northwest Territories.

4. Canadian Journal of Botany 51:421-427

5. Original

6. a. Yukon; Mackenzie Mountains

   b. Alpine; Overburden, Roads, Tailings

7. Vegetation of the MacMillan Pass area (63 15 N, 130 04 W), on the border between the Yukon and Northwest Territories, was analyzed for copper, molybdenum, manganese and zinc after geochemical surveys had identified the area as characterized by abnormally high molybdenum levels in Paleozoic shales, soils and stream sediments.

Abnormally high plant molybdenum values, up to 52 ppm dry weight, occurred in the diverse flora that was growing on neutral or slightly alkaline molybdeniferous soils derived from shale-limestone parent materials. The molybdenum content of plants reflects quite closely the soil content and soil reaction.

On acid molybdenum soils, shrubs, lichens and woody species had low and rather uniform molybdenum content, although higher levels were found in *Epilobium augustifolium, Epilobium latifolium, Calamagrostis canadensis* and *Festuca altaica*. This is in sharp contrast to the increased uptake of molybdenum by plants on neutral or mildly alkaline soils (values in excess of 5 ppm and up to 52 ppm).

Greatest concentrations of copper and zinc were found in soils derived from Paleozoic limestones. Low, rather uniform values for copper were found for a variety of soil conditions. Greatest differences in zinc content of plants occurred between species rather than between habitats. *Betula* and *Salix* accumulated appreciably more zinc than did the conifers, grasses and forbs. Manganese content was greatest for the woody species, and decreased with increasing soil pH.

Very low levels of all four trace elements are characteristic of *Cladonia alpestris*. The diversity of flora over the calcareous molydenum-rich soils was striking compared to the flora over the surrounding acid soils. The diversity of species on the relatively alkaline soil may reflect the greater availability of combined nitrogen. Several leguminous species such as *Lupinus arcticus* and *Astragalus umbellatus* were abundant where calcium and molybdenum were readily available, but few plants of these species occurred on the acid soils. Molybdenum plays a role in nitrogen-fixation by legumes

1. DUNBAR, G.A.

2. 1971

3. The effectiveness of some herbaceous species for montane and subalpine revegetation.

4. Proceedings of the New Zealand Ecological Society 18:48-57

5. Original

6. a. New Zealand

   b. Alpine; Roads

7. This paper reports the results of trials conducted between 1965 and 1971 at three eroded and exposed subalpine sites (3,200-3,700 ft) in the Canterbury Mountains of New Zealand. The objective was to determine: (1) the amount of revegetation on eroded soils and screes and the type of fertilizer necessary for establishment and growth; (2) the establishment of native grass species; and (3) trials comparing establishment and growth of 10 herbaceous species (seven grasses, two clovers and yarrow) sown with and without fertilizer.

The author noted that soil frost and needle ice in these exposed areas makes revegetation difficult. Fertilizer proved to be essential for winter survival. Plants with fertilizer continued steady growth through the summer and autumn, but untreated plants showed little growth after January.

Holcus lanatus produced the most vigorous growth and best groundcover rapidly. White clover and *Trifolium dubium* were two of the poorer species. In general, the seeds of several species gave satisfactory germination and establishment from surface broadcast seeding when aided by a complete fertilizer.

Fertilizer mixtures, where applied, consisted of superphosphate and calcium ammonium nitrate each at 502 kg/ha, magnesium sulphate and potassium sulphate each at 125.5 kg/ha, copper sulphate and zinc sulfate each at 11.2 kg/ha, borax at 22.4 kg/ha and sodium molybdate at 0.35 kg/ha.

In the absence of continued fertilizer applications, all plots showed progressive deterioration in groundcover after the second season although *Agrostis tenuis*, white clover and *Holcus lanatus* were well able to volunteer from self-seeding. *Agrostis tenuis* and Chewings fescue (*Festuca rubra* ssp *commutata*) established and grew more slowly but were

Continued ...

Dunbar, G.A. 1971. Continued

more persistent over five growing seasons than *Holcus lanatus*. A high incidence of volunteers on some plots was attributed to bare areas in host plots in the early years when a residual fertilizer effect was apparent.

Despite differences in slope and aspect of the exposed trial sites, most species did not show significant differences in effectiveness on the different sites. The rate of deterioration of plant stands over the study period was also similar at all sites.

1. DVURECHENSKII, V.N. and V.I. FEDOTOV

2. 1974

3. Relict and rare flora on mine dumps in the central chernozem region.

4. Soviet Journal of Ecology 5:371-373

5. Original

6. a. U.S.S.R.; East Siberian Taiga

   b. Alpine, Southern Yukon, Southwestern Mackenzie; Overburden

7. Surface mining in the Central Russian Highlands has resulted in exposure of chalk and limestone along the bottoms and sides of pits. These exposures are a substrate for natural revegetation, involving a number of local plants but also a relict flora of the low alpine type.

Although none of the species of this relict flora are native to northern Canada, it is relevant to note that some relict plant species can have a high mobility when man-made disturbances are available as habitats for colonization. In this study, the authors noted that the man-made chalk and limestone exposures had an extensive growth of relict and rare plant species because the disturbance had created a microclimate more suitable to these species than was available in the surrounding natural habitat. Dumps are, of course, overgrown more rapidly with a relict flora if the dump is adjacent to natural relict species populations.

Some of the relict plant species have been successfully cultivated in Russia and the authors concluded that many relict and rare calciphile species can be used for revegetation of exposed chalk and limestone beds.

1. EAMAN, T.

2. 1974

3. Plant species potentials for high-altitude revegetation.

4. In: Proceedings of a Workshop on Revegetation of High-Altitude Disturbed Lands, Environmental Resources Center, Information Series 10, Colorado State University, Fort Collins, Colorado, p 39-43

5. Original

6. a. Colorado; Rocky Mountains

   b. Alpine; Overburden, Roads

7. Potentially useful species for revegetation at high-altitudes must be perennial, environmentally adapted, and must have available seed supplies. A list of such species includes those relied on in Rocky Mountain revegetation programs: smooth brome, orchardgrass, timothy, intermediate wheatgrass, pubescent wheatgrass, slender wheatgrass, Kentucky bluegrass, mountain brome, Russian wildrye, blue wildrye and big bluegrass. Of these, mountain brome, slender wheatgrass, blue wildrye and big bluegrass are the only native species used to any extent for high elevations. Slender wheatgrass is easily established but not long-lived. Other potentially valuable native species are tufted hairgrass (*Deschampsia caespitosa*), sheep fescue (*Festuca ovina*), Thurber fescue (*Festuca thurberi*) and Parry oatgrass (*Danthonia parryi*), all natives of high elevations in Colorado.

Seed is available for only a very few of the adapted native grasses. Grasses have a longer history of use in re-seeding programs but forbs and shrubs also have potential. However, research results so far are inadequate to provide information for choosing grasses, either native or introduced, that have the highest potentials for stabilizing soils on disturbed sites at high altitudes in the Rocky Mountains.

1. ECHOLS, J.W. and R.L. CUANY

2. 1974

3. Seed supplies and plant materials work group summary.

4. In: Proceedings of a Workshop on Revegetation of High-Altitude Disturbed Lands, Environmental Resources Center, Information Series 10, Colorado State University, Fort Collins, Colorado, p 83-87

5. Original

6. a. Colorado; Rocky Mountains

   b. Alpine; Overburden, Roads

7. Seed supplies of grasses for forage and soil conservation fall into two classes: (1) those in adequate supply but high-priced (many more than $1/lb) - smooth brome, orchardgrass, timothy, Kentucky bluegrass, intermediate wheatgrass, pubescent wheatgrass and crested wheatgrass (the latter for drier areas); (2) those in short supply and very high-priced - tall wheatgrass, most fescues, perennial ryegrass, meadow foxtail, slender wheatgrass, Russian wild rye and other species for dry temperate areas.

Legume seed is more available. Alfalfa price varies between $1.50 and $2.00/lb, with red, alsike and white clover, sweetclover, sainfoin, milkvetch, birdsfoot trefoil and crownvetch at various prices up to $ 4.75/lb.

A critical need exists for new plant materials and screening for desirable types. Several grasses, sedges, legumes, forbs and shrubs have potential for high-elevation reclamation, including the following: high altitude *Carex* and *Juncus* spp., *Deschampsia caespitosa, Dryas drummondii* (for rock fill and other disturbances), the alpine clovers (*Trifolium* spp.) and *Sedum*.

An appendix tabulates over 50 grasses and legumes and lists the seeding rate, average number of seeds per pound, and their typical purity and germination percentages.

1. EK-JANDÉR, J. and G. FÅHRAEUS
2. 1971
3. Adaptation of *Rhizobium* to subarctic environment in Scandinavia.
4. Plant and Soil, Special Volume 1971:129-137
5. Original
6. a. Finland, Norway, Sweden; West Eurasian Tundra, Fennoscandian Highlands

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Growth experiments were performed at 20° C and 40° C using isolates of strains of clover rhizobia from subarctic locations in Finland, Sweden and Norway (68° to 70° N) and from more southerly locations in Sweden (south of 63° N). *Trifolium repens* was nodulated with *Rhizobium trifolii* strains of different geographical origin. The isolates from the subarctic region showed a better adaptation to low temperature than isolates from more southern areas. At 10° C, the northern isolates grew faster, nodulated their host plants earlier and showed more vigorous acetylene reduction than the southern isolates. For both strains the most rapid cell multiplication occurred at 20° C with little difference between the two strains. Nitrogenase activity of the subarctic *Rhizobium* strains also showed better adaptation to the lower temperature.

Information is lacking on the competitive abilities of subarctic *Rhizobium* strains. However, the adaptation of this species to a cold climate and short growing season may have practical application for plantings in cold soils.

1. ELLIOT, C.R. and H. BAENZIGER

2. 1973

3. Creeping red fescue.

4. Canada Department of Agriculture, Ottawa. Revised Edition, 19 p

5. Original

6. a. Canada

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Included in this description of the characteristics, adaptation, varieties and uses of creeping red fescue (*Festuca rubra*) are the following points relevant to reclamation. This species is useful in reclaiming burned-over bushlands where, if seeded in early spring after a burn, it will reduce water and wind erosion and be a valuable forage species. It is especially suitable for regrassing disturbed areas around industrial sites. For this latter purpose, a seeding rate of 10 to 12 lb/acre (11 to 13 kg/ha) is suggested.

Creeping red fescue is a perennial, fine-leaved, hardy, turf-forming grass with an extensive, fibrous root system. Because of its creeping habit it is unlike the sparse ground cover of bunch grasses but also is not as aggressive as the strongly creeping bromegrass. It grows better on poor soils than either Kentucky bluegrass or timothy (which needs more moisture) but is less drought-resistant than crested wheatgrass. It is virtually unaffected by frost and can provide winter pasture without injury.

Cereal companion crops tend to retard development of fescue seedlings. Much nitrogen is needed for seed production and when nitrogen is low the seed production falls off. If grown in a mixture with one or more legumes this species has an improved quality and forage yield.

1. ELLIOTT, C.R. and J.L. BOLTON
2. 1974
3. Licensed varieties of cultivated grasses and legumes.
4. Canada Department of Agriculture, Publication No. 1405. Looseleaf binder with variable paging
5. Original
6. a. Canada

   b. Yukon and Northwest Territories; Overburden, Roads, Tailings

7. This two-volume handbook, one for grasses and one for legumes, is in looseleaf form to allow descriptions of new crops and varieties to be added after they have been licensed. Descriptions are arranged in alphabetical order by the common names of the crops, and varieties are arranged alphabetically for each crop. Photographs are in color to aid the recognition of distinguishing characteristics of each crop species.

Each grass and legume is represented by a one-page description opposite color photographs of the plant, of its seed (actual size), and its seed magnified. For each variety, data include the license number, date licensed, breeder, origin of breeding stock, breeding method, description of the variety, basic stock, seed distributors, and geographic areas of adaptation.

Copies of this handbook are available for $15.00 from the Information Division, Canada Department of Agriculture, Ottawa, K1A 0C7.

1. ENVIRONMENT CANADA, NORTHWEST REGION, PACIFIC REGION

2. 1976

3. Environmental information for mining developments in the North.

4. Environmental Protection Service, Environment Canada. Environmental Impact and Assessment Report EPS-8-NW-76-1. 25 p

5. Original

6. a. Canada

   b. Yukon and Northwest Territories; Overburden, Roads, Tailings

7. This report advises Territorial Water Boards of the information required for environmental evaluation of mining projects on federal lands. In general terms, the Department of Environment needs a description of the project, characteristics of the environment, the interaction of the project and the environment, and safeguards or measures to minimize environmental damage. A recommended table of content includes: the proposed development; the total development concept; a full description of the ore body (including the acid-generating potential of the ore and waste rock); the method of mining, manner of waste rock disposal, and extent and character of surface disturbance; details of processing; tailings disposal including acid-producing potential; tailing pond design and regulation; management of miscellaneous waste; mineral production, storage and transport; supporting industrial services; and abandonment, which includes plans for stabilization and reclamation of all disturbed lands and tailings impoundment areas.

Information is also requested on the characteristics and conditions of the existing environment including: terrain and geology; hydrology; climate; biological characteristics; terrestrial flora and fauna (particular attention should be given to distribution and successional trends as influenced by landforms, climatic variables, fire history and current or past land-use patterns); and freshwater and marine flora and fauna.

A statement of present land and water resource use and status is necessary; it should include an assessment of the potential uses and land capability so that a judgement can be made of uses and resources foregone if mining development occurs. The proponent of development is requested to estimate the frequency, intensity, duration and geographic magnitude of the effects of all phases of the project which may have an

Continued ...

Environment Canada, Northwest Region, Pacific Region. 1976. Continued

influence on the environment, including physical, biological and chemical changes. Details of planned programs for mitigation and compensation of adverse effects and the effectiveness of these actions should also be included.

A final section lists the federal acts and regulations of environmental significance and their administering departments which apply to northern mining developments, namely the Fisheries Act, Canada Water Act, Clean Air Act, Ocean Dumping Act, Migratory Birds Convention Act, Arctic Waters Pollution Prevention Act, Navigatible Waters Protection Act, Northern Inland Waters Act, and Territorial Lands Act (Territorial Land Use Regulations). The addresses and telephone numbers of Department of Environment Regional Offices across Canada are also noted.

1. EPPS, A.C.

2. 1973

3. Uses of woody and herbaceous ornamental ground cover materials.

4. In: 1973 Alaska Revegetation Workshop Notes, Co-operative Extension Service, University of Alaska, p. 45-50

5. Original

6. a. Alaska; Central Alaska Taiga, Southern Alaska Taiga, Alaskan Tundra

   b. Alpine, Southern Yukon, Northern Yukon, Yukon Coast, Mackenzie Delta Region, Central Mackenzie, Southwestern Mackenzie; Overburden, Roads

7. Woody plant and herbaceous plant materials can provide a satisfactory ground cover with minimum care and lower maintenance costs than grasses in many cases. Although taller than grasses, their low form is amenable for ground cover and they are becoming more popular for landscape of highways in Alaska. Some species also provide aesthetic value. Those of ornamental interest in addition to their use as ground cover are: dwarf caragana (*Caragana pygmaea*); cinquefoil (*Potentilla fruticosa*); Indian snowberry (*Symphoricarpos orbiculatus*); bearberry (*Arctostaphylos uva-ursi*); lingonberry (*Vaccinium vitis-idaea*); and juniper species.

Plants which can withstand high acid native soils with pH below 4.5 levels, which grasses cannot tolerate, are the mountain buttercup (*Ranunculus montanus*), bog-rosemary (*Andromeda polifolia*), dwarf caragana (*Caragana pygmaea*), wintergreen (*Gaultheria procumbens*), cinquefoil (*Potentilla fruticosa*) and sedges.

Difficult wet sites could be planted with herbaceous moss sandwort (*Arenaria verna caespitosa*) or the woody bog-rosemary and wintergreen which tolerate prolonged flooding.

Native willows are a readily obtainable woody plant material which roots rapidly and stabilizes the soil. Tip cuttings (the upper 12 to 18 inches of willow shoots) are collected in March or early April, tied in bundles with the base wrapped in wet paper towels, and then stored in plastic bags in a deep freezer until planting time. In late May or early June cuttings are planted in soil to one half their depth at 18 inch intervals. Normally 80% of the cuttings take root and establish plants. The low growing types of willows provide good cover at relatively low cost.

Ground cover species with drought tolerance include: yarrow (*Achillea millefolium*), pink milfoil (*Achillea millefolium rosea*), dusty miller (*Artemisia stelleriana*), dwarf caragana, junipers (*Juniperus chinensis*

Continued ...

Epps, A.C. 1973. Continued

sargenti, Juniperus horizontalis and *Juniperus horizontalis plumosa*), cinquefoil and Indian snowberry. All of these can withstand drought conditions that are intolerable to grasses.

On steep banks or rocky slopes the junipers are ideal selections. Large, healthy plants should be selected over small, immature plants. Herbaceous perennials are not good for steep banks especially where snowmelt in spring causes serious erosion problems. Some means to prevent erosion in addition to the plantings is advisable while the plants become established. Close spacing and plantings along small ditches that follow the bank's contour help to circumvent erosion. Mulches of hay or straw also help to hold the soil intact.

A possible problem with the use of woody species, especially along highways, is their attraction to wildlife as browse. In particular, native willows are the primary browse of moose. Also, spacings of plantings must take into consideration the size at maturity of the plant and the potential for soil erosion in the early phases before there is a high degree of cover from the shrubs.

For both herbaceous and woody ground covers, the soil needs careful preparation, preferrably before planting. The soil should be a minimum of 6 inches deep or better still 8 inches deep. Soil tests will determine fertilizer requirements. The first two growing seasons determine the success of such plantings and fertilizers can determine the success of the revegetation program.

Moisture content of the soil during the initial two years is a chief factor to consider in maintenance. The correct choice of species for a situation also minimizes maintenance costs. Fertilization of woody and herbaceous ground covers is not normally required after establishment. In cases where soils lack available nutrients, supplemental fertilization of 80-160-80 lb N,P,K/acre should be applied. The best season for application is early spring; fertilizer should be applied when the foliage is dry, unless watered in at once, to prevent burning of the foliage.

It is best to obtain northern grown seed or nursery material for best climatic adaptation. Many native plants are not commercially available but use of special techniques can encourage them to establish. Lingonberry and bearberry can be established by 3 ft^2, 4 to 6 inch deep transplanted sods. These need to be dug and put in place within 24 to 48 hr after removal and should not be allowed to dry out.

The greater initial cost of establishment of woody species is offset by such long term benefits as little maintenance and effectiveness on sites where grasses will not establish. In certain circumstances it is also desirable to use woody species in addition to grass seeding.

1. EROS, G.

2. 1976

3. Questions and answers about Prillcote seed.

4. In: Proceedings of the Inaugural Meeting Canadian Land Reclamation Association, Crop Science Department, Ontario Agricultural College, University of Guelph, Guelph, Ontario, p 28-32

5. Original

6. a. Ontario; Canadian Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Prillcote seed is processed with a coating that contains additives for improved germination and seedling establishment. The coating is tailored to the seed type and the soil and growing conditions of an area. Legume seed coatings contain rhizobia, nutrient for the rhizobia, trace elements, phosphorus and lime. The correct strain of *Rhizobium* is carefully selected.

The proximity of the nutrients and rhizobia, the prolonged viability of the rhizobia and improved water relationships are all advantages of such a coating system. The coating also protects seeds from diseases, insects and birds.

The same seeding rate is used for coated seed as for uncoated seed. The cost per pound is the same for uncoated seed. With improved rate of establishment and survival, the actual cost per established plant is less. Storage life is also the same as for bare seed, bearing in mind that rhizobia-inoculated seed should be stored under cool, dry conditions and used within six months.

Coating of the seed increases the seed size by 15 to 20% which requires adjustment of openings in seeding equipment. If used in a hydroseeder, coated seed should be added to the mix last and used without delay. Lime added to the coating mix aids establishment of alfalfa in acid soils. Once established, the alfalfa will survive on soils normally too acid for alfalfa establishment. Coated seed can also be seeded in accompaniment with fertilizer without harm.

At the time of this report, OSECO Ltd which produces Prillcote seed had nine species available as coated seed, including three alfalfa, Leo birdsfoot trefoil, Empire birdsfoot trefoil, Penngift crownvetch, Toro timothy, Baylor bromegrass and Tetra alsike clover. A full range of coated seed is planned for spring 1977, from a plant operating in southern Ontario since 1976. Several other companies also offer pre-inoculated and coated seed.

1. ERRINGTON, J.C.

2. 1975

3. Natural revegetation of disturbed sites in British Columbia.

4. University of British Columbia, Vancouver, B.C. Ph.D. Thesis. 145 p

5. Original

6. a. British Columbia; Coastal, Interior

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. This study examined the factors that affect natural revegetation of two particular types of disturbance: (1) areas disturbed by airborne emissions of the Anyox smelter on the northern coast of British Columbia; and (2) areas where vegetation and soil were totally removed by mining and industrial activity at mine waste dumps on Vancouver Island and in the West Kootenays, and on abandoned logging roads on Vancouver Island and in the interior of British Columbia.

In the study of abandoned logging roads in the Interior Douglas Fir Zone, the author noted that most colonizing species favoured the road surface rather than the upslope or downslope sides of the roads. Revegetation of these abandoned logging roads seemed to be governed by the length of time since abandonment and the moisture deficiency on slopes.

Fifteen mine sites of varying ages were sampled in the Interior Western Hemlock zone at elevations from 2,600 to 5,400 feet with some sites close to the Engelmann Spruce - Subalpine Fir Zone. Some of these mines were in operation as late as the 1950's. On these mine dumps, the following species occurred quite often: *Pseudotsuga menziesia, Thuja plicata, Picea glauca, Salix* spp. and *Alnus tenuifolia*. Amongst the herb species were *Epilobium angustifolium* and *Anaphalis margaritacea*. Grass and *Carex* species occurred often but no species was dominant by itself. Two moss species were notable, *Rhacomitrium canescens* and *Polytrichum juniperinum*.

The steep, unstable slopes of these waste mounds is one of the major reasons why plant colonization is slow. Species which colonize disturbed areas are generally present in the adjacent plant community or are dispersed as light, wind-blown seed from a greater distance. If the seed source is diverse, the probability of successful colonization will be greater. If the disturbance covers a large area, there is more reliance on wind-borne seed dispersal as a source of colonizing species.

Continued ...

Errington, J.C. 1975. Continued

Vegetative reproduction is limited to the edges of disturbed areas. Thus the only species with significant potential to revegetate a large proportion of disturbed areas are those with easily dispersed seeds.

Alder is the only nitrogen-fixing species to attain any degree of dominance. However, it is present only in coastal areas and does not tolerate areas where moisture is deficient.

Three major factors limit growth on disturbed materials: moisture, slope stability and nutrients. Of these, moisture is the most important.

The size of a disturbance may either magnify or obscure many of the factors important to successful revegetation. For moisture, adverse conditions of slope and aspect can be minimized on smaller disturbances through provision of shade. Inducement of microrelief is a way of conserving moisture on waste dumps. Plant succession on large-scale disturbances will usually require more time.

In summary, four steps to successful reclamation were recommended by the author:

1. Establish objectives for future land-use;

2. Assess the major problems for revegetation (moisture status, slope stability, nutrient status);

3. Modify waste dumping procedures to minimize as many critical factors as possible; and

4. Plant the species which will satisfy the objectives for future land use.

1. ETTER, H.M.

2. 1971

3. Preliminary report of water quality measurements and revegetation trials on mined land at Luscar, Alberta.

4. Northern Forest Research Centre, Edmonton, Alberta. Internal Report NOR-3. 19 p

5. Original

6. a. Alberta; Rocky Mountains

   b. Alpine, Southwestern Mackenzie, Southern Yukon; Overburden

7. Preliminary information is reported for seeding on weathered sandstone and shale overburden in the Upper Foothills at an altitude of 5,500 ft near Luscar, Alberta. The overburden dump after 25 to 30 years had almost no vegetation.

Fall and spring hydroseeding was done with a basic slurry consisting of 1,000 gal/acre of cellulose fibre mulch at 800 to 1,000 lb dry weight/acre, 10-30-10 inorganic fertilizer at 200 lb/acre, 46-0-0 urea at 100 lb/acre and activated sewage organic fertilizer at 200 lb/acre.

Five mixtures of seed were used, the first two of which contained the most common erosion control grasses and legumes. These two mixes were the only applications assessed in this report. The vegetation cannot be completely assessed until three to four years after the seeding was carried out. The species comprising these two seed mixes are given below:

Mix I

Agropyron cristatum	Crested wheatgrass
Agrostis alba	Redtop
Festuca rubra	Creeping red fescue
Poa pratensis	Kentucky bluegrass
Melilotus alba	White sweet clover

Mix II

Agropyron riparium	Streambank wheatgrass
Bromus inermis	Smooth brome
Elymus junceus	Russian wildrye
Phleum pratense	Timothy
Medicago sativa	Alfalfa

Etter, H.M. 1971. Continued

Spring seeding proved superior to fall seeding for both sweet clover and alfalfa but had little significance for grasses. The 0 to 6% slope produced the highest density of vegetation in almost every case, and the steepest slope was much inferior. Density of plants was considered satisfactory for erosion control except for the steepest slope, provided satisfactory growth and development prevailed. The density of plants in the first year was limited by the number of suitable microsites and not by the rate of seeding or species mix. Even under the most favourable conditions, only 10% of possible germinants were obtained and the higher number of potential germinants in mix I had little effect on those actually obtained. This was attributed to the limited number of microsites suitable for germination and early growth. Such microsites, depressions created by the tracks or blade of a bulldozer during grading and usually 2 to 3 inches in diameter and 1 to 2 inches deep, have great importance to the success of germination. Mulch and seed wash into these depressions or are covered by fine particles that move downslope or by wind. It is recommended that the seeding slurry be concentrated in the microsites and that the total area of microsites be increased. On rocky ground the slurry can be washed into crevices. On smooth or sandy surfaces contour trenches can be created and the seed covered and packed.

Several subjects were recommended for further study: (1) the importance of surface topography on seed germination and plant establishment on rocky and sandy gravel; (2) the engineering methods to produce optimal surface topographies for plant establishment or placement of seeds in suitable microsites; (3) the optimum density and arrangement of plants with particular root structures for stabilizing steep slopes; and (4) coordination of mining and reclamation plans to achieve a desirable topography (slope, aspect, mass stability, and drainage) before reclamation. The author suggested that once these problems were solved greater attention could be given to selection of species, land-use objectives, and reclamation technique apart from hydroseeding.

The remaining portion of this study was directed to the measurement of water quality changes due to accelerated erosion. Coal particles were found to move from the mined-land into the associated drainage system (Camp, Cabin, and Luscar creeks and ultimately Gregg River) during spring runoff and at intervals during May and June.

1. ETTER, H.M.

2. 1973

3. Mined-land reclamation studies on bighorn sheep range in Alberta, Canada.

4. Environmental Conservation 5:191-195

5. Original

6. a. Alberta; Rocky Mountains

   b. Alpine; Overburden

7. Winter forage for ungulates in Alberta between the elevations of 4,500 ft (1,372 m) and 7,000 ft (2,134 m) is primarily in grassy subalpine openings on west- to southeast-facing slopes which are bordered by open, mixed or coniferous forests. Several ecological factors combine to make the amount and quality of winter range of great significance to the maintenance of bighorn sheep herds in the Rocky Mountain foothills of Alberta. Restriction or deterioration of winter range may cause malnutrition at a season when climatic factors are most severe and the carrying capacity of these winter ranges is basic to the management and conservation of bighorn sheep herds.

Developmental activity, in particular surface mining, could completely destroy this winter range. Coal leases overlap 50% of the estimated 390,000 acres of winter bighorn sheep range in Alberta, of which 5% has been explored for mining. The success of displacement of the sheep from their winter range is dependent on the accessibility of alternative range.

Another concern is for the quality of range after mining and reclamation are completed. Grasses, sedges and legumes constitute 80 to 90% of the bighorn sheep's diet which means that there are at least 30 potential forage species of *Poa, Carex* and legumes which occur naturally in the foothills. However, none of these are commercially available as seed nor have they been used on disturbed land. Plant trials conducted by the Canadian Forestry Service near Luscar, beginning in 1970, were aimed at selecting plants and techniques for revegetation of such mined land. Several species have shown promise for revegetation of winter range: *Agropyron cristatum, Agropyron trichophorum, Elymus junceus, Festuca rubra, Phleum pratense* and *Medicago sativa*. *Elymus junceus* and *Festuca rubra* have known value for protein and phosphorus for range cattle but this has yet to be established for bighorn sheep.

Etter, H.M. 1973. Continued

The possible success of revegetation with these species is dependent on the placement of top-soil prior to seeding. However, if seeding is done on spoil without amelioration to the physical, chemical and biological properties, it may take decades to produce a productive range. The plants should be established in a pattern useful to sheep. For example, grasses and forbs should be grown on south-facing slopes and shrubs and trees on north-facing slopes. Because the south-facing slopes are more likely winter range for sheep, such limited soil supplies as are available should be utilized on these slopes, then stabilized with grasses and legumes. Priority should be given to those south-facing slopes with 20 to 47% (10 to 20°) steepness. Hydroseeding has proved itself as a method for revegetating rugged terrain, using a slurry of water to which is added organic mulch, fertilizer, adhesive and seeds.

Continuing research is necessary to assess the productivity of reclaimed land in the subalpine zone and to determine the carrying capacity of reclaimed range.

1. F.F. SLANEY and COMPANY LIMITED

2. 1974

3. Environmental considerations, proposed northern railway extension, Whitehorse to Pelly River.

4. Unpublished report prepared for White Pass and Yukon Corporation Limited, Vancouver, by F.F. Slaney and Company Limited, Vancouver. 129 p

5. Original

6. a. Yukon; Southern Yukon

   b. Southern Yukon; Roads

7. Specifications for the revegetation of disturbed sites expected in the construction of this proposed northern railway are that artificial reseeding and fertilizing will be necessary to establish a quick cover of vegetation. A mix of grass and legume species should be formulated for the various types of soils, slopes, aspects and moisture regimes encountered in the region. Fertilizer applications should be based on site-specific soil analyses with slow release NPK fertilizer preferred.

Hand seeding is necessary on areas under five acres in size, and hydroseeding is recommended for larger sites. However, a good water source is required for mixing and application of the seed-fertilizer-mulch slurry.

A main problem with revegetation programs for the central Yukon is the low rainfall, short growing season and cold winter. Grass and legume species potentially suitable and tolerant of such conditions are:

Crested wheatgrass	*Agropyron cristatum*
Intermediate wheatgrass	*Agropyron intermedium*
Pubescent wheatgrass	*Agropyron trichophorum*
Red top	*Agrostis alba*
Smooth brome	*Bromus inermis*
Creeping red fescue	*Festuca rubra* (Boreal strain)
Durar hard fescue	*Festuca ovina duriscula*
White sweet clover	*Melilotus alba*
Rhizome alfalfa	*Medicago sativa*
Canada bluegrass	*Poa compressa*

1. FARMER, E.E., B.Z. RICHARDSON and R.W. BROWN

2. 1976

3. Revegetation of acid mining wastes in central Idaho.

4. U.S. Department of Agriculture, Intermountain Forest and Range Experiment Station, Ogden, Utah. Research Paper INT-178. 17 p

5. Original

6. a. Idaho; Rocky Mountains

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. A two-year revegetation program at the copper-cobalt Blackbird Mine in the Salmon National Forest, Idaho, involved the use of three seed mixes (native species, introduced species, and a mixture of native and introduced species) on three types of level overburden material (a control plot on overburden material, an irrigated plot on overburden material, and overburden material topdressed with approximately 8 inches of soil originated from nearby forest lands). Soils and overburden were not homogeneous; spoils and ore-dumps ranged from innocuous to highly toxic with severely phytotoxic "hotspots" particularly difficult to revegetate.

All the overburden materials needed lime which was topdressed at the rate of 800 lb/acre. Two months before planting the overburden material was ripped to a 10-inch depth and the sites harrowed after liming.

A minimum combination of treatments necessary to provide an acceptable plant cover was not evident from the first two years but the authors were able to suggest treatments that may be most acceptable. These are top dressing of mining wastes with native topsoils or subsoils to an 8-inch depth and an accompanying fertilization program. Irrigation proved of questionable value. Revegetation of raw mining wastes, even with the addition of lime, fertilizer and mulch was not considered a desirable alternative. A basic, unanswered question regarding supplemental irrigation is what happens when irrigation ceases.

No significant adverse effects on germination were observed on the top dressing material or lime-adjusted mining waste. Furrow seedbed preparation and seed packing are essential to ensure hydraulic contact. Special measures may be required to ensure hydraulic seed contact in rocky waste piles.

Species evaluation so far indicated that introduced grasses will produce good stands under the best conditions, native species will provide some

Continued ...

Farmer, E.E., B.Z. Richardson and R.W. Brown. 1976. Continued

cover under adverse conditions, and admixtures of native and introduced species will provide stands across a wide range of intermediate soil conditions. Phytotoxic materials such as sulphide minerals and salts will require burying and will probably not support vegetation. Based on the data of two growing seasons, orchardgrass, timothy and smooth brome produced good grass stands especially on areas topdressed and fertilized. A mix which incorporated these with native pioneer species (squirreltail, yarrow, cheatgrass and possibly hairgrass at this location) was expected to show good production and ground cover under good growing conditions with a capability of producing an adequate stand under adverse conditions.

Initial fertilization is a requirement but it is not known how long its effects last or if fertilization will be a continued requirement at periodic intervals. Reacidification is an expected problem. Analysis of the plant tissues from strongly acidified and moderately acidified soils indicated that the content of potassium, iron, copper and zinc was greater for plant tissues on soil of pH 3.4 than in those of pH 5.0. No adverse vegetative effects of reacidification have occurred to date on the plot topdressed with 8 inches of native topsoils and subsoils.

1. FOOTHILLS PIPE LINES LTD.
2. 1975
3. Mackenzie Valley Pipeline Inquiry in the matter of Phase II - The impact of the pipeline and Mackenzie corridor development on the physical environment. First Panel on Phase II. Subjects relating to the physical environment.
4. Prepared evidence of Dr. H. Vaartnou, Foothills Pipe Lines Ltd., Calgary, presented to Mackenzie Valley Pipeline Inquiry, p. 28-35
5. Original
6. a. Mackenzie District; Canadian Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region; Roads

7. A summary of the answers given by Dr. H. Vaartnou, consultant to Foothills Pipe Lines Ltd. on matters of revegetation indicate that the objective of the contractor is to help restore a self-supporting ecosystem along the proposed pipeline right-of-way and in other areas disturbed by construction of the pipeline. This will be done as much as possible by using ecotypes of species currently found in the area.

Plans are to use fast growing native grasses and naturalized landraces of introduced grasses, selected from various locations in the Mackenzie Valley, as opposed to the agronomic species chosen for use by Canadian Arctic Gas Study Limited. Also, seed of native legumes and native shrubs will be used, if possible. For areas difficult to rehabilitate by seed, vegetative propagation will be used through the technique of shredding, using rhizomes, stolons, root stocks and stem cuttings. Riverbanks may be hand planted using stem cuttings and rooted cuttings.

Native species are defined as species developed through natural evolution in a certain geographical area. A naturalized landrace is an introduced species adapted to local environmental conditions and able to survive in competition with native species. An agronomic species is a variety of an introduced or native species developed for forage or for landscaping purposes. Ecotypes of natural varieties are developed in local micro-environmental conditions and are adapted to certain soil and climatic conditions. Different ecotypes may have different demands for soil type, nutrition, moisture, and temperature, and may vary in disease resistance, competitive ability, seasonality, root system and cover production.

Continued ...

Foothills Pipe Lines Ltd. 1975. Continued

An advantage of using native ecotypes of a particular region is that they are suited to the local environment, provided they are planted in similar situations. Planting a diversity of species of local genetic origin is also a safe strategy against pests and diseases such as snow mold.

In relation to a fertilizer program the suggested strategy was to promote top growth only where it is needed for permafrost protection. Minimal amounts of fertilizer are intended so that there will be minimum disruption of the natural ecosystem and because native species do not require as much fertilizer as commercial agricultural varieties.

The methods of revegetation planned by Foothills Pipe Lines Ltd. are: (1) aerial seeding by helicopter as much as possible; (2) Brillion ground seeding where seed must be incorporated into the ground, followed by harrows, rollers or other equipment according to the ground surface; (3) shredded native ground cover for vegetative propagation for species which cannot be propagated by seed. The material for shredding will be obtained from the top growth plus two to four inches of soil (containing the roots and rhizomes) along the pipeline ditchline. This material would either be used immediately on adjacent areas or stored for later use.

Specific areas which may need ground equipment for seeding are riverbanks, borrow pits, construction sites, some steep slopes, some loose sandy soils, and small areas around compressor stations.

The proposed method of vegetative propagation differs from sodding because in the former case shredded material is incorporated into the existing surface, whereas with sodding the applied layer is superimposed over an existing surface. Roots in the sod may not extend into the soil surface and may remain in the applied layer if the surface soil texture is different from the applied layer. This situation is susceptible to sub-surface erosion between the layers, especially on slopes.

Native species and naturalized landraces of introduced species are not yet commercially available. However, Foothills Pipe Lines Ltd. has contracted to grow sufficient seed over a two to four year period depending on the variety and quantity required. Multiplication was proposed to start in the spring of 1976 and sufficient seed was expected to be available to revegetate 1,000 acres by 1978, 3,000 acres by 1979 and a much greater quantity by 1980.

Monitoring and evaluation of the revegetation success would be directed by a plant scientist with regular inspection by supervised technicians through aerial and ground surveys. Areas failing to rehabilitate would be revegetated at the first opportunity.

The author was of the opinion that there is no reason why disturbed areas could not be rehabilitated using current scientific knowledge, technology and experience. To ensure maximum success, native species adapted to the local environment should be used from the beginning.

1. FOOTHILLS PIPE LINES LTD.

2. 1975

3. Revegetation

4. In: Environmental Statement, Section D, Part 5 of Application before the National Energy Board and to the Department of Indian and Northern Development. Part 5.6.12, Page 5D-5.27

5. Original

6. a. Mackenzie District; Canadian Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region; Roads

7. The applicant indicated that the three basic types of surfaces that will require rehabilitation are:

1. Surfaces on which the ground vegetation and surface organic layer remain relatively intact. Such surfaces would include those under snow roads, the working area adjacent to the pipeline trench, and the area used for the temporary storage of pipeline backfill;

2. Surfaces from which the ground vegetation and organic layer has been removed, exposing mineral or organic soils. These would be found in borrow pits, on side hill cuts, and along the ditch line;

3. Surfaces created by deposition of material. These would be found in areas occupied by temporary roads, wharves, and stockpiles.

Sites with an intact organic mat will require the least intensive revegetation efforts. In most cases, seeding and fertilizing will be adequate. Borrow pits and cuts will require more intensive methods such as: scarification, addition of organic matter, use of unseeded or seeded mats, planting of shrub cuttings, use of soil stabilizers, and fertilization.

Deposited material will likely create the most difficult rehabilitation problems. Two basic types are anticipated: native backfill forming the pipeline berm; and relatively coarse textured material used for select backfill and for road and pad construction. Much of the native backfill could be adequately treated through application of fertilizer and seed. In wet areas vegetated by rhizomatous grasses and sedges, replacement of the sod or clumps, plus fertilization, may be sufficient to restore a healthy natural plant cover. Select backfill and granular material used in pad and road construction will require more intensive treatment, such as: use of preseeded mats; selection of plant species adapted to granular well-drained substrates; enhancement of surface moisture regime through shrub and tree plantings; intensive seeding and fertilizing; application of fine-textured material to aid water retention; and mechanical loosening.

1. GARDINER, R.T.

2. 1972

3. Cominco approach to revegetation research.

4. In: Environmental management: the mining scene, reclamation of disturbed land areas, Centre for Continuing Education, University of British Columbia, Vancouver, B.C. 6 p

5. Original

6. a. British Columbia; Rocky Mountains

   b. Alpine; Overburden

7. The revegetation program of Cominco Ltd. includes a three-part investigation: 1)characterization of the disturbed area with respect to climate, natural vegetation and potential land use; 2) characterization of mine and mill waste with respect to suitability as a growth medium for plants combined with greenhouse growth studies of selected species; and 3) *in situ* evaluation of plant species and revegetation techniques.

Growth limiting factors characteristic of waste mine rock from Fording Coal Company, B.C., for example, were severe deficiencies of nitrogen and phosphorus, rather than the presence of phytotoxic compounds.

The wide range of geographic location, elevation and the variable nature of disturbed sites in British Columbia make it especially important to conduct *in situ* studies of the variables affecting revegetation.

Preliminary results of *in situ* investigations at Fording Coal have found:

1. Wheat grass and fescue species and smooth brome appear best adapted to climatic conditions at elevations ranging from 5,500 to 7,300 feet. Sweet clover, alfalfa and sainfoin grew satisfactorily at 5,500 and 6,700 feet; but growth at 7,300 feet was poor. The primary objective of this study was to screen grass and legume species on the basis of ability to adapt to climatic conditions at high elevations. Seed was applied by hand to a well prepared seed bed. Sixteen grass and nine legume species were included initially. The study has since been modified to include a total of 18 grass and 14 legume species and varieties.

2. When seeded on road embankments using hydroseeding techniques, grass species showing most promise during the initial growing season were timothy, creeping red fescue, Durar hard fescue, Canada bluegrass, smooth brome, several wheatgrass species and red top. Sweet clover was the most promising legume followed by alfalfa, sainfoin and alsike clover.

Continued ...

Gardiner, R. T. 1972. Continued

3. The available moisture supply and the physical condition of the road embankment soil surface had an important effect on germination and establishment of grass and legume seedlings. The glacial till road embankment soils become very hard on drying. As a result, growth was concentrated in microsites and in erosion rills which remained moist and soft long enough for seedlings to establish. Mulching materials effectively held the seed on steeply sloping surfaces but did not appear to reduce moisture loss from evaporation.

4. Forage yield on alpine grassland big game range was almost doubled by application of 200 lb nitrogen per acre. Nitrogen was the single most important nutrient limiting growth of alpine grasses. Residual effects of fertilizer on yield were impossible to determine due to inadequate regrowth following sampling.

Seed of Engelmann spruce and lodgepole pine has been collected for propagation of planting stock at Cominco's nursery at Trail, B.C. and for eventual *in situ* evaluation. Cuttings of aspen and willows native to the Fording Valley will also be propagated, as will seedlings from eight different clones of hybrid poplar for plantings at several Cominco properties.

1. GEALE, C.H.
2. 1966
3. Guides for controlling erosion.
4. Alberta Department of Lands and Forests, Edmonton. 39 p
5. Original
6. a. Alberta; Canadian Taiga, Rocky Mountain

   b. Southwestern Mackenzie, Southern Yukon; Roads

7. The major portion of this guide is devoted to the control of erosion through good road design and maintenance and use of diversion ditches, obstructions and contour trenches. Recommendations for plantings for northern Alberta include grass species in a mixture with a clover species as follows:

	MIXTURE	RATE/ACRE
1.	Kentucky bluegrass (*Poa pratensis*) or Canada bluegrass (*Poa compressa*)	6 lbs
2.	Creeping red fescue (*Festuca rubra*) or Timothy (*Phleum pratense*)	6 lbs
3.	Alsike clover (*Trifolium hybridum*) or White Dutch clover (*Trifolium repens*)	3 lbs

Kentucky bluegrass was chosen for its very fine, thickly branched root system that occupies 1.5 to 2.0 feet of soil. Canada bluegrass also produces an abundance of creeping root stocks that form a close turf. It grows 6 to 8 inches high, is more aggressive than Kentucky bluegrass and flourishes in a wide variety of soils.

Crested wheatgrass, suggested for southern Alberta mixtures, is deeper rooted than Kentucky bluegrass with roots that penetrate 6 or more feet which makes this species drought resistant. Limited stalk growth of crested wheatgrass makes it less of a fire hazard. This latter species is the main distinction between the species mixes recommended for southern and northern Alberta regions. Timothy is regarded as a relatively poor choice because of its height and thus fire danger.

Of the two legumes, Alsike clover is considered a good choice as it supplies an extensive root system with limited above ground growth. However, white Dutch clover and alfalfa are good substitues for Alsike.

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Geale, C.H. 1966. Continued

Alternate grass species to those listed above are intermediate wheatgrass (*Agropyron intermedium*) and pubescent wheatgrass (*Agropyron pubescens*). The latter is a strong creeping perennial which is easy to establish and has early spring growth. Both species are strongly recommended for erosion control although their abundant top growth is a fire hazard.

A section of this guide book diagrams the correct procedure for tree planting with a planting bar to ensure correct depth and firm soil about a seedling. Trees are considered valuable where erosion is excessive and where permanent and durable protection is required. Species mentioned for Alberta are spruce (*Picea glauca*) and pine (*Pinus contorta*) planted at 10 ft x 10 ft spacing.

1. GILL, D.

2. 1974

3. Habitat enhancement in a disturbed northern landscape.

4. In: D. Hocking and W.R. MacDonald, Editors, Proceedings of a Workshop on Reclamation of Disturbed Lands in Alberta, Northern Forest Research Centre, Information Report NOR-X-116, p 79-80

5. Original

6. a. Yukon; Southern Yukon

   b. Alpine, Southern Yukon; Overburden

7. One aspect of disturbances that has received little attention is the potential for some disturbed sites to ultimately enhance habitat values for wildlife. The example is given of the Burwash Uplands, Yukon Territory, an alpine tundra environment, where in the late 1880's a wagon road was established to the gold fields and subsequently used until the 1930's.

The original plant cover has been replaced by a plant cover different from the sedge-tussock tundra of the area which is underlain by high ice-content permafrost. It is believed that thermokarst degradation along the trail created moist depressions which were colonized by willow and ground birch. The new terminal shoots of willow are a preferred browse of caribou and these animals follow the old roadway while feeding. Such concentrations of caribou, involving a herd of approximately 200 animals, maintain the degradation along the trail so that moist depressions have remained and normal plant succession has been repressed.

This disclimax plant association of the trail had greater species diversity than the surrounding area and greater annual productivity. Microtines and birds also use the disclimax vegetation for food and cover.

The findings of this study are believed to have significance for habitat manipulation in the North.

1. GIVEN, D.R. and J.H. SOPER

2. 1975

3. Pioneer vegetation on moraines near Clachnacudainn Snowfield, British Columbia.

4. Syesis 8:349-354

5. Original

6. a. British Columbia; Rocky Mountains

   b. Alpine; Overburden

7. Glacial recession has exposed moraine surfaces near the Clachnacudainn Snowfield, located near the centre of Revelstoke National Park where seven sites at an elevation between 6,700 to 7,650 ft were examined. Collections and observations were made at the eastern margin of the snowfield and immediately north of Mount Clotz. Since 1948 there has been little change in the extent of ice adjacent to the main snowfield on the north side of this mountain. Soil formation in this area is extremely slow. The quartzites and granites yield a thin gritty or sandy, dark, structureless soil which is occasionally silty and often partly frozen.

Colonization of the freshly exposed moraines is believed to be by chance dispersal of propagules from adjacent vegetation. The relatively prominent species are those which possess features making them suitable colonizers, such as *Epilobium latifolium*, a gregarious species which spreads by rhizomes and seeds. This is a ubiqutous species of gravel moraines and floodplains in the Arctic, and was also the first species to appear on Mount Robson moraines. *Carex nigricans* occurred at four sites and is an aggressive species. *Antennaria alpina* spreads by seeds and stolons and appears at a slightly later stage of succession.

Similar species have been reported from other accounts of moraine colonization. In the Selkirk Mountains, *Epilobium latifolium* was more common on younger moraines and *Juncus drummondii* and *Juncus mertensianus*, present as a minor species in this Mount Revelstoke National Park study area, were reported as the most common plants of young moraines.

Twelve species were listed for the calcareous moraines of Sir Sanford Glacier of which several (*Epilobium latifolium, Erigeron acris, Poa alpina, Salix arctica, Salix nivalis, Silene acaulis* and *Trisetum spicatum*) also occur at Clachnacudainn Snowfield. At Glacier Bay, Alaska, pioneers on moraines were mosses, *Epilobium latifolium, Equisetum variegatum* and *Dryas drummondii*, which were followed by *Salix arctica* and other prostrate and shrubby willows. Herbaceous legumes were inconspicuous in the Revelstoke alpine flora, and the important primary pioneer *Dryas drummondii* was absent from such high elevations.

1. GOFF, L.D.

2. 1971

3. Erosion control research in the Swan Hills.

4. Alberta Forest Service, Department of Lands and Forests.
   Unpublished Report. 92 p

5. Original

6. a. Alberta; Canadian Taiga

   b. Southwestern Mackenzie, Southern Yukon; Roads

7. The development of a major oil field and removal of forest caused a severe erosion problem in the Swan Hills of Alberta. An erosion control research program was initiated in 1966 and the results are summarized in this report.

In the study area, a structureless silty-clay loam of loose-grained particles is very susceptible to sheet and rill erosion. There is also a medium-grained sand infiltrated with fine montmorillonite clay which is very concretious when dry but very fluid when wet. Where these subsoils are exposed, it is not uncommon to find rills and gullies cut into the surface 5 ft or more. Water is the main agent of erosion.

There is an apparent inability of natural vegetation to return to cleared sites. Native grasses and forbs of the area are accustomed to growing in humus and lack the ability to grow on mineral soil. Many areas cleared in early development of the oil field are still bare. However, mineral soil is a good seedbed for natural regeneration of pine, spruce and poplar but considerable time is needed for their establishment to be a sufficient cover to prevent erosion. Interim cover must be supplied by grasses and legumes.

Rehabilitation involved seven progressive steps for re-landscaping the damaged sites (essentially an engineering phase) and for establishing a vegetative cover to stabilize the soil.

1. Re-landscaping is necessary to improve drainage characteristics where moderate to severe erosion occurs, and where levelling provides a better growing surface. Surfaces left in a cloddy and rough state assist in moisture absorption and impede runoff waters. Two methods of runoff control, check dams and contour trenching of long backslopes or landfills, were used.

Continued ...

Goff, L.D. 1971. Continued

2. The degree of seedbed preparation (levelling, harrowing, and scarifying) had a distinct influence on subsequent vegetation growth. Growth response was best on worked surfaces. Spring seeding, in particular, required that the seed be harrowed into the soil; this increased plant success by at least 50%. However, with fall planting it made little difference whether seed was worked into the soil or not. Experimental planting of cereal grain companion crops required harrowing both before and after the seed was broadcast to prepare a deeper more uniform seedbed required for cereal grains.

3. Seeding time must coincide with favourable moisture conditions, the most important factor in establishing forage stands. Seeding can in general be done at three times of the year: spring seeding completed by mid-June; early fall seeding from late July to early September; and late fall seeding after September 30 and extending through to freezeup. Early spring seeding is often hampered by poor ground conditions too soft for machinery to work. Late spring plantings often suffer from a rapid loss of surface moisture which can be offset somewhat by working the seed into the soil by harrowing or, more effectively, by sowing cereal grain companion crops for surface mulching. Without some protection against moisture loss or crusting, the germination of grasses and legumes sown during the spring is very slow. Early fall seeding is subject to the same disadvantages as late spring seeding with the added disadvantage that a companion crop cannot be sown at this time of year. Legumes in particular suffered high mortality at this time. Late fall seeding proved to have many advantages and has been most successful. With late fall seeding, seed is on the ground to take advantage of early spring moisture and ground conditions in the fall are ideal for preparing the seedbed and landscaping. One disadvantage of late fall seeding is the mortality of legume plants from overnight frosts during early spring.

4. Grasses and legumes were selected on the basis of trials and are rated in order of decreasing priority:

Grasses	Legumes
Timothy	Rambler alfalfa
Creeping red fescue	Red clover
Kentucky bluegrass	White dutch clover
Crested wheatgrass	
Pubescent wheatgrass	
Brome grass	

Both germination and growth characteristics of timothy were superior to all other grass species at this location. A mixture of these species was applied at the rate of 40 lb/acre but subsequent trials suggested that the Kentucky bluegrass and the white dutch clover be dropped. When a surface mulch or companion crop was used the legumes were dominant; without the mulch or companion crop the grasses were dominant.

Continued ...

Goff, L.D. 1971. Continued

5. Fertilizer rates of 200 to 250 lb/acre of 16-20-0-14 ammonium nitrate-phosphate-sulfate compounds applied with the seed were found to give optimum results. A second application of 50 to 100 lb/acre was required the following spring with a companion crop. Sub-soils exposed by construction for roads and well sites were very strongly acid, some as low as 4.0 pH. It was considered impractical to use lime and it was decided that it could be accepted that vegetation would be sparse and patchy where soils were very acid.

6. The use of cereal grain nurse crops increased legume growth only when sown with spring seed applications on dry exposed surfaces and slopes. The soil was also stabilized sooner by the faster germination and growth characteristics of cereal grains. In this case Oli barley was found to be the most successful companion crop. Re-fertilization of the forage crop was a very necessary step in the following year because of the heavy drain of nutrients from the soil by the companion crop.

7. Mulches proved beneficial in two ways: for stabilizing steep slopes until vegetation was established and growing conditions were improved; and improved moisture retention and prevention of surface crusting of the soil. All of the types of mulches tested were relatively successful (turfiber, straw and asphalt, sawdust and asphalt, jute mesh, straw, plastic netting and brush). Seed and fertilizer were broadcast in late fall after the brush mulch was applied. Slight erosion still occurred but this was minor and there was no movement of the seed. The cover provided by the brush mulch aided moisture retention and prevented surface crusting and was less restrictive to penetration by plant growth than any other mulch type. It also had the advantage of being readily available and on newly constructed sites the cleared debris can be used and applied fairly easily by a dozer and some hand work. The main disadvantage is that it is a fire hazard but this is not considered serious because of a lack of fuel continuity.

The author concluded for the Swan Hills that there are two seasons of the year when vegetative cover can be best established: in spring and late fall seed applications. Spring treatment requires landscaping to improve drainage and seedbed preparation in which the surface is harrowed or scarified if the soil is compacted. Once the seedbed is prepared, seed is applied by either broadcasting or hydroseeding at a rate of 40 lb/acre with 200 to 250 lb/acre of fertilizer 16-20-0-14 which is worked with the seed into the soil. A nurse crop of barley is recommended for all well-drained and exposed surfaces. A brush mulch is then spread over the steep slopes and small problem areas where it is impossible or impractical to sow a companion crop. Refertilizing is necessary in the following spring when a companion crop is sown.

The only differences with a late fall treatment are that the surface should be left in a cloddy condition to improve moisture absorption and to encourage slow runoff. It is also not necessary to prepare the site further for fall seeding nor does seed applied in the late fall need to be worked into the soil if the surface is left in a roughened condition. A mixture of several or more grasses and legumes should always be used to allow for wide variations of soil and climate.

1. GOODMAN, G.T., C.E.R. PITCAIRN and R.P. GEMMELL

2. 1973

3. Ecological factors affecting growth on sites contaminated with heavy metals.

4. In: R.J. Hutnik and G. Davis (Editors). Ecology and reclamation of devastated land. Proceedings of a N.A.T.O. Advanced Study Institute on the Ecology and Revegetation of Drastically Disturbed Areas held at the Pennsylvania State University, University Park, Pennsylvania, August 3 to 16, 1969. Volume 2, p 149-173.

5. Original

6. a. Wales; British Forest

   b. Yukon and Northwest Territories; Overburden, Tailings

7. This paper discussed attempts to revegetate abandoned smelter wastes of copper, zinc, lead and iron in the Swansea Valley, one of the largest single concentrations of industrial dereliction in the United Kingdom. The authors pointed out that agriculturally productive grass swards are not a revegetation objective in such areas because any grass produced may be toxic to livestock. However, visually acceptable swards can be obtained with methods described by the authors.

Experiments to evaluate the short- and long-term success of these swards show that although large enough quantities of heavy-metal tolerant seed are very difficult to obtain, these strains require less soil treatment and are more productive and persistent than commercial (non-tolerant) grass varieties, particularly in less toxic wastes. However, even highly tolerant grass varieties are of little value on very toxic sites without the incorporation of an organic amendment.

It seems fairly clear that metal-tolerant clones would grow better than commercial (non-tolerant) varieties under equivalent conditions. It was also clear to the authors that surface applications of inexpensive forms of organic matter (sewage sludge or domestic refuse) would produce an acceptable sward for 5 or 6 years but regression would follow without additional top dressing of organic matter. The cost of this every 3 or 4 years must be set against the cost of a seed multiplication program to provide enough tolerant seed to sow on unamended (but fertilized) waste tips.

Continued ...

Goodman, G.T., C.E.R. Pitcairn and R.P. Gemmell. 1973. Continued

A seed multiplication program is made more difficult by the fact that non-tolerant strains often grow better than tolerant on normal soil and vice versa on waste. This would mean that if the multiplication were done on ordinary nursery soil, a genetic selection for non-tolerance would ensue, and so the program must be carried out in a toxic-waste area of some size. With this balance of costs, it is probably better to pay for liberal organic-matter dressings and use commercial varieties if the acreage of metal-contaminated land to be treated is small and very toxic.

1. GRELLER, A.M.

2. 1974

3. Vegetation of road cut slopes in the tundra of Rocky Mountain National Park, Colorado.

4. Biological Conservation 6:84-93

5. Original

6. a. Colorado; Rocky Mountains

   b. Alpine; Roads

7. Road cut slopes adjacent to Trail Ridge Road and Fall River Road in the alpine tundra of Rocky Mountain National Park, Colorado, were studied in terms of pioneer vegetation. Tundra plants find it difficult to occupy steep, coarse, unstable slopes left by cut and fill operations and 40 to 50 years after disturbance succession plays a minor role on these slopes. Live plant coverage was about half that of natural cushion plant stands.

Analysis of eight study sites indicated that north-facing slopes and areas with late-snow cover are dominated by *Poa fendleriana*. South-facing slopes were dominated by *Agropyron scribneri*. Distinct plant assemblages exist on north-facing and south-facing slopes, a situation which may be controlled by soil moisture.

Stabilization, increased soil moisture and increased organic matter facilitate plant colonization of denuded sites. A flat disturbed area with moist humus-rich soils was dominated by cushion plants and a few graminoids, and had the greatest coverage of all categories of plants.

The data from this study suggested a recovery time of greater than 50 years before roadbank vegetation begins to resemble the live plant coverage of the sparsely vegetated natural stands. Invasion by soil and rock lichens may take much longer.

The main pioneer species effective in stabilizing the soil immediately around them were: *Agropyron scribneri, Poa fendleriana, Trisetum spicatum* and *Poa glauca*. When several tussocks have stabilized an area, then mat and cushion plants plus other types enter the site. Little competition seems to exist within these grass tussocks, in sharp contrast to the cushions of *Arenaria* spp, *Trifolium* spp, *Silene acaulis* and others.

1. GRIGGS, R.F.
2. 1956
3. Competition and succession on a Rocky Mountain fellfield.
4. Ecology 37:8-20
5. Original
6. a. Colorado; Rocky Mountains

   b. Alpine; Roads

7. A potential invasion sequence is described for alpine fellfield plants of Rocky Mountain Park in Colorado. All the characteristic species of the fellfield are pioneer species capable of colonizing bare ground. The cushion plants, with their characteristic dense, round, flat form and long tap roots, are invaded by seedlings of many other tundra plants. Thirty-three species were observed to invade such cushion plants as *Silene acaulis*; 22 were seen invading *Arenaria obtusiloba*, 10 invaded cushions of *Paronychia pulvinata*; 21 invaded *Trifolium nanum* and seven *Trifolium dasyphyllum*. In addition 93 invader-host pairs were determined and the list is not yet complete.

The direction of invasion is virtually always the same; rarely was an invading species seen to be invaded by its host. The author suggests a tentative competitive ladder for the species concerned and poses the question of whether a similar pattern of invasion and succession occurs in other arctic-alpine areas. *Silene acaulis*, for example, occurs in almost every arctic and alpine habitat from the Rocky Mountains north to Ellesmere Island. Several writers from circumpolar locations have reported *Silene acaulis* cushions to harbour foreign species.

1. GULLEN, K.W.

2. 1976

3. Revegetation of tailings areas at vacated mines near Carcross, Yukon Territory.

4. In: Annual Report 1975-76, Boreal Institute for Northern Studies, University of Alberta, Edmonton. p. 18

5. Author's abstract

6. a. Yukon; Southern Yukon

   b. Southern Yukon; Tailings

7. The objectives of the research project were to determine types of vegetation compatible with northern environmental conditions and the unique soil characteristics in the tailings areas and to develop soil treatment techniques for obtaining maximum growth in this unique soil.

The following research procedures were involved: (1) testing tailings material for grain size and agricultural suitability; (2) establishing a meteorological station for on-site weather observations; (3) establishing test plots with each plot having a specific treatment and fertilizer combination of seed; (5) monitoring growth; and (6) replanting plots where growth was inhibited.

Field work was carried out on two tailings ponds at vacated mines near Carcross, Yukon Territory: Arctic Gold and Silver Mine and Venus Mine.

No growth was achieved at Arctic Mine due to a very low pH and a high concentration of aluminum in the tailings material. Further study is necessary to determine a feasible method for revegetating under these conditions.

The field work at Venus indicated that full-scale revegetation could be economically undertaken by applying at least 100 pounds/acre of a seed mix containing slender wheatgrass, creeping red fescue, smooth brome grass, climax timothy, and inoculated trefoil. Application of 100 pound/acre nitrogen, 300 pound/acre phosphorus, and 100 pound/acre potassium would produce maximum growth.

1. HARRISON, J.E.

2. 1973

3. Environmental geology - mountain coal mining, Alberta and British Columbia.

4. Geological Survey of Canada, Ottawa. Paper 73-A:184

5. Original, with portions of author's abstract

6. a. Alberta, British Columbia; Rocky Mountains

   b. Alpine, Southwestern Mackenzie, Southern Yukon; Overburden

7. Preliminary analyses of geological, geomorphological and hydrogeological factors affecting coal resource exploration, exploitation and reclamation in the Crowsnest Pass - Elk Valley area of Alberta and British Columbia included 13 surface mine locations, plus a greater number of pits and waste rock dumps. These analyses indicated that:

(1) Natural revegetation rarely occurs on slopes in excess of 30 degrees and the probability of successfully reclaiming such slopes without regrading is hampered by downslope creep of the surface material.

(2) Downslope creep, while sufficiently rapid to hamper revegetation, does not move a volume of material sufficient to regrade the slope over an acceptable period of time (less than 50 years). Creep movement tends to shorten the steep slope segments rather than reduce slope angles.

(3) Infiltration on most spoil is sufficiently high that run-off is available to form rills and gullies. The exception is where areas of drainage accumulation occur uphill from the spoil. Slope regrading by running water is therefore not an important process.

(4) Mineralogical and chemical changes at the surface appear minimal although physical breakdown of the softer rock types is rapid in many cases.

(5) Most slope failures are intimately related to moisture, usually in the form of water ponded uphill.

(6) Limited data suggest that failures on active spoil dumps are preceded by an accelerating creep phase offering the possibility of predicting such movements. Investigation of the exact mechanism of failure is continuing.

1. HARRISON, J.E.

2. 1974

3. Some basic data with respect to coal mine waste reclamation.

4. In: D. Hocking and W.R. MacDonald, Editors, Proceedings of a Workshop of Disturbed Lands in Alberta, Northern Forest Research Centre, Information Report NOR-X-116, p. 30-36

5. Original

6. a. Alberta, British Columbia; Rocky Mountains

   b. Alpine, Southwestern Mackenzie, Southern Yukon; Overburden, Tailings

7. The objectives of the Environmental Geology - Mountain Coal Mining Project, conducted on 13 surface mine locations in the Crows Nest Pass - Elk Valley area of Alberta and British Columbia, were: (1) to develop a mapping technique to give the distribution and engineering characteristics of surface materials; (2) to develop and conduct tests to characterize the physical nature of coal mine waste; and (3) to investigate the active natural processes affecting coal spoil and the relationship between these processes and reclamation.

A flexible mapping legend system was used to show the traditional landform divisions (alluvial, lacustrine, till, etc.) and texture. The major map units were described in terms of their engineering properties and rated for suitability as aggregate source, building site, road and rail location and erosional stability. Six physical properties of the soil were measured in the field: temperature, bulk density, water content, infiltration rate, grain size, and lithic composition.

It was found that coal spoil can become extremely hot on south and southwest slopes. Temperatures as high as 164° F were recorded on south-facing 26° slopes, and a 50° F temperature difference between maximum temperatures of north and south aspects were found for 26° slopes. Nature of the surface material and aspect were the main factors governing temperature. Steepness of slope was less important and elevation did not have a noticeable affect.

Two factors were found to influence in-place bulk density: the material and compaction history. As bulk density and compaction values increase, infiltration and water permeability values decrease. For reclamation, it is difficult for plant roots to penetrate highly compacted areas. Weathered bedrock, till and spoil of a dump platform were found to have the highest bulk densities of 100 to 115 lb/ft^3, compared to slurry deposits in a tailings lagoon with 45 to 55 lb/ft^3 densities.

Continued ...

Harrison, J.E. 1974. Continued

Water content measurements indicated that coal spoil water-holding capability is considerable, averaging 10% at 4 to 6 inches depth, and 16% for a similar level in fine coal tailings. However, water is rarely available because the water table is deep and capillary rise through spoils rarely exceeds 2 ft.

The infiltration rates on tailings ponds and coarse spoil were above the rate of precipitation of most summer storms, but compacted pit roadways and finer spoil from weathered surface rock did not take up the rainfall, with overland flow and gullying resulting.

Tailings from the cleaning plants averaged 74% coal particles or highly carbonaceous shale and the remainder was ash. The waste rock was more variable and contained 5% till or weathered rock, 55% shale and carbonaceous shale, and 40% sandstone. For reclamation purposes, the sandstone was the greatest challenge because of its size and resistance to breakdown when it is on the surface.

Several natural active processes were examined as part of this study, of which two, landslides in waste rock and downslope surface movement, were the most important. Surface movement on spoil slopes is a function of slope angle and material. Dump failure by landslide is a major problem during and immediately following placement. As coal spoil has no cohesion, the angle of internal friction must be close to the angle of repose, 37%. The biological angle of repose is the slope angle at which plants can colonize the surface, a value which varies with conditions. From observation of the Crowsnest Pass spoil piles, this angle is between 25° and 30°. This is 7° to 12° less than the physical angle of repose. Surface movement of individual particles on slopes greater than the biological angle of repose was sufficiently rapid to jeopardize the revegetation effort. For coal spoil of sand and pebble size, rates ranged from 30 g/day/m on a 28° slope to 160 g/day/m for a 35° slope. Highest values recorded on a 37° slope were 1600 g/day/m. Movement occurred as irregular, discrete events, and was measured as the number of grams of material that would pass an imaginary line 1 m long in a 24 hr day.

Based on these findings, three recommendations were made:

1. Slopes on waste piles should be reduced to the biological angle of repose where revegetation is required. This is most economically achieved by placing material during mining in such a manner to facilitate reclamation. The contoured dumping system could be adopted at many mines;

2. South slopes should be planted to grass and an annual nurse crop in early spring and tree species should not be introduced until grass cover is well established;

3. All areas above dumps, but especially compacted roads and dump platforms, should be provided with drainage that directs water away from spoil dumps.

1. HARRISON, J.E.

2. 1977

3. Summer soil temperature as a factor in revegetation of coal mine waste.

4. Geological Survey of Canada, Ottawa. Paper 77-1A:329-332

5. Original

6. a. Alberta, British Columbia; Rocky Mountains

   b. Alpine, Southwestern Mackenzie, Southern Yukon; Overburden, Tailings

7. High summer soil temperatures are an important factor in revegetation. This was observed in the Crowsnest Pass area of Alberta and British Columbia during reclamation investigations of coal mine waste dumps.

Highest surface temperatures occur in the fine grained, highly carbonaceous waste produced by the mine cleaning plant.

Experiments conducted to evaluate temperature changes with time for variations in slope, aspect, elevation, and depth indicated that soil water infiltrates into the soil rapidly and that capillary rise from the water table does not supply any water to the upper 90 cm. Once the top few centimeters dry out, no water is available at the soil surface to reduce the high temperature. Sapling roots may have sufficient water levels and leaf temperatures may be below lethal levels, but stems are damaged by high soil temperatures.

The thermal properties of these tailings are such that the surface becomes very hot, but little of the energy penetrates to raise the temperature at depth. The black colour of the material means that little energy is reflected and the absorbed energy raises a very thin layer of the surface to unusually high temperatures.

Revegetation of such areas can be accomplished only with a method that protects the plants or reduces the temperature. This could involve: (1) keeping the surface moist; (2) changing the surface colour with mulch; or (3) establishing a rapidly growing shrub or grass which will cover the surface before midsummer. Trees and shrubs can be protected by: (1) placing slit paper or aluminum plates around their bases; (2) planting them where there is shade to the stem during midday; or (3) providing a nurse crop of grasses or shrubs to shade the surrounding ground. Other less practical measures include increasing soil density by compaction or adding noncarbonaceous material and provision of artificial shade by snow fences or jute netting.

Continued ...

Harrison, J.E. 1977. Continued

The cheapest and most practical method is to leave a hummocky surface or to create microrelief on flat areas and then to plant quick growing grasses which will establish before midsummer. Only when the grasses are well established should shrubs and trees be planted on north-facing sides of hummocks or depressions.

1. HAWK, A.

2. 1973

3. Maintenance of revegetative grass seedings.

4. In: 1973 Alaska Revegetation Workshop Notes, Cooperative Extension Service, University of Alaska, p. 41-44

5. Original

6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga

   b. Alpine, Southern Yukon, Northern Yukon; Roads

7. Adequate maintenance cannot be avoided in revegetation practice without increasing significantly the risk of failure. Revegetation is broadly of two kinds: stands of lawn-like turf dependent on intensive management and high fertilization rates; or extensive seeding with the primary purpose of creating a protective cover with less intensive management. Cost factors and the combination of adverse site conditions (droughty, wet, acid, shallow, or gravelly) make maintenance critical in northern areas.

On any site over a period of years the introduced plant community will be invaded by native plants and eventually revert to a native or near-native composition adapted to that particular site. This process can be prevented or delayed by specific management. The ultimate goal in extensive seeding is to accomplish reversion to a self-perpetuating native plant cover with virtually no maintenance needs and maximum protection from hardy adapted plants. After an interval of 10, 20 or 30 years, only remnants of introduced species would remain in a formerly planted area. The speed and composition of the reversion can be manipulated by fertilization, mowing or spraying but eventually fireweed, yarrow, bunchy grasses and woody species would invade.

Erosion is usually associated with wind and rain. In Alaska, the critical problem on silty soils occurs during spring breakup when the soils tend to flow as snowmelt runs off. Rehabilitation of these sites involves re-establishment of the organic surface insulation. The encouragement of rapid initial heavy growth provides protection, increases moisture-holding capacity, reduces the effect of sudden thaw and provides a source of slowly released fertility.

Ways of speeding up this reversion process needs study. Increased fertilizer rates and number of applications have been tried but the cost and value of this practice in terms of time to complete rehabilitation

Continued ...

Hawk, A. 1973. Continued

have not been evaluated. Fertilizer rates of 30-60-30 or 60-60-60, with two years follow-up fertilization, are typically necessary in the cold Alaskan soils. Fertilization is most effective when applied early in the spring, as soon as snow runoff is completed (for hydroseeders or aerial applications), or as soon as the soil is firm (for ground application).

Maintenance of a grass stand necessitates control of woody plants, primarily alder, and two options exist: mechanical or hand brush cutting; and herbicide sprays. Both of these have disadvantages. A well maintained grass stand can, however, be highly competitive.

1. HERNANDEZ, H.

2. 1972

3. Surficial disturbance and natural plant recolonization in the Mackenzie Delta region.

4. In: L.C. Bliss and R.W. Wein, Editors, Botanical Studies of Natural and Man-Modified Habitats in the Eastern Mackenzie Delta Region and the Arctic Islands, Arctic Land Use Research Programme, Indian and Northern Affairs, Ottawa. ALUR 71-72-14, p 143-174

5. Original

6. a. Mackenzie District; Canadian Tundra

   b. Mackenzie Delta Region; Roads

7. This study sought to quantitatively assess surface soil and plant disturbance and natural plant recolonization on seismic lines and winter roads of known age in tundra and forest-tundra plant communities of the Tuktoyaktuk Peninsula.

The grasses, *Arctagrostis latifolia, Calamagrostis canadensis* and *Poa lanata* appeared to be the best pioneers of totally disturbed moist to dry areas. Also common were *Luzula confusa, Epilobium angustifolium* and *Senecio congestus* in moist to dry areas and *Arctophila fulva* and *Carex aquatilis* in wet areas. This was particularly evident on 1965 seismic lines in which 100% exposure of mineral soil had occurred.

If the peat layer is not removed then wetland communities and dry dwarf shrub-heath areas disturbed in winter regenerate from undisturbed roots and rhizomes. Revegetation of areas disturbed by summer activities takes many years and is initially by species not common to the adjacent undisturbed areas. For example, *Arctagrostis latifolia, Calamagrostis canadensis* and *Poa lanata* occupy less than 1% of undisturbed plant cover normally.

Old vehicle tracks at Tuktoyaktuk, 15 to 20 years after they were made through dwarf shrub-heath tundra, consisted of ruts with bare soil at the bottom and extensive growth of *Arctagrostis latifolia* along the sides.

Succession on seismic lines will occur with a typical willow community, mosses and an *Arctostaphylos rubra* carpet. This last species regenerated from root stock on a seismic line initially 98% bare, and willow and alder were present in the second summer. On a winter road in an upland area where mineral soil was exposed, *Rubus chamaemorus* was the species with most rapid recovery.

1. HERNANDEZ, H.

2. 1973

3. Revegetation studies - Norman Wells, Inuvik and Tuktoyaktuk, N.W.T. and Prudhoe Bay, Alaska.

4. In: L.C. Bliss, Editor, Botanical Studies of Natural and Man-Modified Habitats in the Mackenzie Valley, Eastern Mackenzie Delta Region and the Arctic Islands, Arctic Land Use Research Program, Indian and Northern Affairs, ALUR 72-73-14 and Environmental-Social Committee Northern Pipelines, Task Force on Northern Oil Development Report 73-44, p 45-76

5. Original

6. a. Mackenzie District; Canadian Taiga, Canadian Tundra

   b. Central Mackenzie, Mackenzie Delta Region; Roads

7. This report contains a summary as of August 1972 of revegetation experiments established in 1970 and 1971 by Younkin at Inuvik and Tuktoyaktuk and by Wein in 1971 at Norman Wells, Inuvik and Prudhoe Bay. Several new experiments established in 1972 are also reported here.

Some of the key conclusions and recommendations by the author were:

1. Three species have consistently proven most successful in tundra areas and are among the most successful in producing an excellent ground cover in forested areas by the second year. They are (a) Arctared creeping red fescue, (b) Boreal creeping red fescue and (c) Nugget Kentucky bluegrass. Other researchers, however, found that after 4 years Arctared was the best species by far (90 to 95% cover) while both Nugget Kentucky bluegrass and Boreal creeping red fescue began to show some winter kill.

2. More species become established, overwinter successfully and grow well in the second year as one goes south into the boreal forest. These species included Meadow foxtail, Slender wheatgrass and Engmo timothy.

3. The legumes Aurora alsike clover and Falcata alfalfa have some limited success in warm exposures from Inuvik south.

4. Species which have proven unsuccessful over one or two years in most tests are Greenleaf wheatgrass, Fairway crested wheatgrass, Streambank wheatgrass, Polar bromegrass, Sawki Russian wildrye, Kall orchardgrass and Leo birdsfoot trefoil on both organic and mineral soils and Imperial and Frontier reed canarygrass on organic soil.

Continued ...

Hernandez, H. 1973. Continued

5. The native grasses, bluejoint (*Calamagrostis canadensis*) and tall arcticgrass (*Arctagrostic latifolia*) establish more slowly than the 3 best species on test plots. However, they are excellent natural colonizers of disturbed areas in the northern boreal forest and tundra.

6. Gravel and other extremely dry areas are the most difficult types of material on which to establish a plant cover.

7. Reseeding does not prevent melt-out and possible subsidence of disturbed areas because plant growth is not fast enough to restore an organic mat in the first year. It can, however, reduce soil erosion. Side slopes in forest areas may be stabilized by the planting of willow and alder cuttings.

8. Establishment of vegetation, naturally or by reseeding, is not able to restore the soil energy budget in tundra areas within the first three years and possibly even longer.

9. The ultimate effects of successful plant establishment on animal behaviour are unknown. Birds have eaten broadcast seed and animals have grazed established test plots. If seeded and fertilized areas prove more palatable or nutritious than the native vegetation and if animals are selective in their grazing, such animal activities could markedly reduce the effectiveness of a revegetation programme. This area of plant-animal interactions is probably one of the most important and least understood aspects of revegetation.

10. Little growth and establishment of the species tested thus far is likely in wet areas. Here, however, regrowth from undisturbed roots and rhizomes of native species is possible.

11. The seed mixes proposed for mesic tundra areas were as follows:

	Weight of seed (lb/ac)	
	Mix of best species	Diverse Mix
Arctared creeping red fescue	13	10
Nugget Kentucky bluegrass	13	10
Tall arcticgrass	8	8
Bluejoint	8	8
Slender wheatgrass	4	3 1/2
Frontier reed canarygrass	4	3 1/2
Engmo timothy	0	3 1/2
Meadow foxtail	0	3 1/2

Nurse crop: If quick growth is desired, 10 lb/ac winter rye may be useful. Frontier reed canarygrass may also act as a nurse crop.

Fertilizer: 100 lb/ac of elemental N and 200 lb/ac of elemental P seem best. Some K would also be useful, possibly in the range of 50 to 100 lb/ac of element.

Continued ...

Hernandez, H. 1973. Continued

12. For disturbances in the boreal forest, the annual cereal nurse crop may be omitted since perennial grasses such as Frontier reed canarygrass, Engmo timothy, Meadow foxtail and Slender wheatgrass should grow quickly in the first year. Tall arcticgrass can probably be omitted for all areas except the northern boreal forest where permafrost is present since it is best adapted in tundra and cold soil areas. Bluejoint should be useful in the boreal forest. Boreal creeping red fescue could possibly be substituted for Arctared in these areas. Legumes, such as Aurora alsike clover and Falcata alfalfa, may prove beneficial in these warmer areas, especially if inoculated with the proper bacteria for nitrogen fixation.

1. HERNANDEZ, H.
2. 1973
3. Natural plant recolonization of surficial disturbances, Tuktoyaktuk Peninsula region, Northwest Territories.
4. Canadian Journal of Botany 51:2177-2196
5. Original
6. a. Mackenzie District; Canadian Tundra

   b. Mackenzie Delta Region; Roads

7. Natural plant recolonization was assessed at several locations on seismic lines and winter roads where they passed through three different plant communities in the Mackenzie Delta and four tundra communities in the Tuktoyaktuk Peninsula.

With winter seismic lines recovery was relatively rapid with most shrub cover regenerating from rootstocks rather than seedlings.

Use of winter roads of compacted snow and ice resulted in areas of bare peat along the travelled centre of the road. Mineral soil was rarely exposed. Winter roads through upland areas removed most of the vegetation cover but the soil energy budget was little affected because the peat layer remained intact. Where mineral soil was exposed, thaw increased 80 to 100%. If the peat layer remained intact, thaw increased 30 to 50%.

Eriophorum vaginatum and *Carex bigelowii* seemed stimulated by disturbances which did not completely eliminate them. *Carex bigelowii* doubled its presence and *Eriophorum* increased its presence threefold on a seismic line disturbance on Richards Island. *Eriophorum* also doubled its production in these circumstances. This is due to the increased thaw after disturbance which results in a larger soil volume and nutrient release and availability which can enhance flowering.

In areas of greater disturbance, on the summer seismic lines of 1965 which resulted in exposure of mineral soil, total plant cover was 43% after 6 years. Species growing on the disturbance were very different from those on undisturbed areas. *Arctagrostis latifolia, Calamagrostis canadensis, Poa arctica* and *Luzula confusa* were the most typical and abundant pioneers on such disturbances on upland mesic sites. On wet sites, the colonizers were predominantly *Arctophila fulva* and *Carex aquatilis* which expand rhizomatously.

1. HERNANDEZ, H.

2. 1973

3. Revegetation studies Norman Wells, Inuvik and Tuktoyaktuk, N.W.T. and Prudhoe Bay, Alaska: Application to the proposed pipeline route.

4. Environment Protection Board, Winnipeg. Interim Report No. 3. Towards an Environmental Impact Assessment of the Portion of the Mackenzie Gas Pipeline from Alaska to Alberta, Appendix V. Revegetation. 127 p

5. Original

6. a. Mackenzie District; Canadian Tundra, Canadian Taiga

   b. Central Mackenzie, Mackenzie Delta Region, Southwestern Mackenzie; Roads

7. Experimental plots at the locations mentioned in the title were established in 1970, 1971 and 1972 to determine the possibility of re-establishing plant cover on disturbed areas in the North. The four sites represent the northern boreal forest, boreal forest to tundra transition, upland dwarf shrub-heath tundra and coastal wet sedge polygon tundra.

Three species (Arctared red fescue, Boreal creeping red fescue and Nuggett Kentucky bluegrass) have consistently proven most successful in tundra areas and are also among the most successful in forested areas for producing an excellent ground cover by the second year. This conclusion is in agreement with several other studies. With increasing distance south into the boreal forest, more species become established, overwinter successfully and grow well in the second year. These include meadow foxtail, Slender wheatgrass and Engmo timothy. Legume species tried, Aurora alsike clover, Falcata alfalfa and Leo birdsfoot trefoil, were successful only in sites and exposures of warm soil, generally from Inuvik south. These plants could prove beneficial for their nitrogen fixing capacity.

The two native grasses included in the total of 27 species tested, bluejoint (*Calamagrostis canadensis*) and tall arcticgrass (*Arctagrostis latifolia*) are prominent colonizers of disturbed sites in tundra and northern boreal forest areas. They proved moderately successful in seeding tests and established more slowly than the three best species mentioned above. Tall arcticgrass is better adapted to tundra and cold soils of forest areas while bluejoint is better adapted to the boreal forest (Younkin 1973).

Continued ...

Hernandez, H. 1973. Continued

Species which have proven unsuccessful in the two years of testing are Greenleaf wheatgrass, Fairway crested wheatgrass, Streambank wheatgrass, Polar bromegrass, Sawki Russian wildrye, Kall orchardgrass and Leo birdsfoot trefoil on both organic and mineral soils and Imperial and Frontier reed canarygrass on organic soil.

Establishment, growth, and flowering were best on mineral soil and poorest on a dry peat mat. When both mineral soil and peat are moist they are better for supporting plant growth, with mineral soil still superior to peat. Gravel proved to be the most difficult material as a plant growth medium and supported little, if any, plant growth. This was particularly true in a comparison of a gravel covered hot oil test pipeline and a mineral-soil cover over a hot gas pipe where the former had virtually no plant cover and the latter the best plant cover and earliest spring growth.

Low seeding rates of 5 to 10 lb/acre used in this study generally gave a 30 to 60% plant cover of the best species by the second year over low berms 5 ft high. Other studies reported high seeding rates which gave 75 to 95% plant cover for the best species for such locations as Prudhoe Bay and Sans Sault Rapids. The best seeding times were early spring or late fall when soil moisture is available. The absence of soil moisture during summer caused reduced establishment, cover, height and flowering of most species seeded at this time.

Fertilizer is a must for good plant establishment. Of the eight different fertilizer treatments tested, those containing phosphorus alone or in combination provided better supporting growth and those containing phosphorus plus nitrogen seemed the best overall. Rates of 100 lb/acre of elemental N and 200 lb/acre of elemental P are best to promote growth, and applications of potassium in amounts of 50 to 100 lb/acre are also useful. The effects of fertilization appeared lost by the second or third year in the northern boreal forest and less so in the tundra areas.

Agronomic species produced flowering heads with viable seed, particularly where the plants had been fertilized. However, the seed of agronomic species did not establish or overwinter in native undisturbed plant communities.

The author noted that reseeding does not prevent melt-out and subsidence of disturbed areas. Plant growth in the first year is not sufficiently fast to achieve this, although it may reduce soil erosion. The natural soil-energy budget of a winter road through an upland tundra shrub-heath community was not restored in the initial three years with natural plant re-establishment or a seeded plant cover. Reseeding in the boreal forest may be more effective because more litter is produced there than on the tundra.

The effect of successful plant establishment on animal populations is not known, although it was noted that birds ate broadcast seed and

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various animals grazed on the established test plots. Grazing of reseeded areas could occur if the seeded and fertilized areas proved more palatable than adjacent areas. The author suggested that this topic is probably the most important and the least understood aspect of revegetation.

Several concerns are listed as information gaps or potential problems. The first is that the transferability of data from small test plots to large areas is not totally known. It is suggested that this could be tested by reseeding areas such as rig sites. Secondly, revegetation studies have not been established in the southern half of the proposed pipeline route where there is a better climate and the area is more similar to southern areas. The long term effects of reseeding in northern areas are not known and the susceptibility of recommended species to diseases in the field is not known. The extent and pattern of natural recolonization of seeded and fertilized areas is also little known. For example, mosses increase greatly in fertilized disturbed areas, whether the areas were seeded or not. The effects of fertilizer on adjacent water bodies is not well documented. There is also a danger that if large areas are reseeded to a relatively uniform expanse of vegetation, the danger of a "crop failure" under adverse conditions is a real danger unless a seed mix including native species is used. Lastly, the ultimate effects of successful plant establishment on animal behaviour is unknown.

Several preliminary recommendations are made regarding reseeding and revegetation based on knowledge at the time that this report was prepared:

1. Extremely dry areas are the most difficult to revegetate naturally or by seeding. Plant cover is naturally low on gravelly eskers and once removed is difficult to replace.

2. Wet tundra areas are also difficult to revegetate as the species tested so far had poor establishment. One possibility is regrowth from roots and rhizomes of native species. If the area's wet conditions are maintained after disturbance, the organic mat may be replaced as blocks of sod or tussocks enabling root and rhizomes to regrow. Such a technique was equally applicable to muskeg and bog in the boreal forest.

3. The most promising technique for slope stabilization is transplanting of willow and alder cuttings plus heavy seeding to grass with some mulching.

4. For mesic tundra areas, plant establishment and growth are best on mineral soil and poorest on a dry peat mat. Replacement of the organic mat is not recommended if seeding is going to take place, but if reseeding is not planned then the organic mat must be replaced for growth from roots and rhizomes, a technique most successful in moister

Continued ...

Hernandez, H. 1973. Continued

areas. Two seed mixes, preliminary in nature, are proposed for the upland dwarf shrub-heath of the eastern Mackenzie Delta and possibly for cottongrass tussock tundra areas along the arctic coast and for alpine areas. The only difference between the two mixes is that one contains two more species (Engmo timothy and meadow foxtail) which gives greater diversity:

	Weight of seed (lb/ac)	
	Mix of best species	Diverse mix
Arctared creeping red fescue	13	10
Nugget Kentucky bluegrass	13	10
Tall arcticgrass	8	8
Bluejoint	8	8
Slender wheatgrass	4	3 1/2
Frontier reed canarygrass	4	3 1/2
Engmo timothy	0	3 1/2
Meadow foxtail	0	3 1/2

If a quick growth is desired then a winter rye nurse crop of 10 lb/acre may be useful. Frontier reed canarygrass may also act as a nurse crop. Fertilizer application should be 100 lb/acre of elemental N and 200 lb/acre of elemental P with possibly 50 to 100 lb/acre of elemental K.

Recommendations for the northern boreal forest are more in the form of suggestions than guidelines until further data are available from studies in this area. The following suggestions are made:

1. The annual cereal nurse crop may be omitted since perennial grasses such as Frontier reed canarygrass, Engmo timothy, meadow foxtail and slender wheatgrass should grow quickly in the first year.

2. Bluejoint is useful in the boreal forest. Tall arcticgrass can probably be omitted for all areas except the northern boreal forest as this species is best adapted to tundra and cold soil areas.

3. Boreal creeping red fescue could be substituted for Arctared creeping red fescue in boreal areas.

4. Legumes (Aurora alsike clover and Falcata alfalfa) can prove beneficial in warmer areas, especially if inoculated with the proper bacteria for nitrogen fixation.

1. HERNANDEZ, H.

2. 1974

3. Possible effects on vegetation of the proposed gas pipeline from Prudhoe Bay, Alaska, and the Mackenzie Delta, to Alberta.

4. In: Environmental impact assessment of the portion of the Mackenzie Gas Pipeline from Alaska to Alberta, Volume IV, Research Reports. Environment Protection Board, Winnipeg. Chapter 3, p 37-68

5. Original

6. a. Mackenzie District; Canadian Tundra, Canadian Taiga

   b. Central Mackenzie, Mackenzie Delta Region; Roads

7. Those agronomically developed grasses best suited to the northern Boreal Forest, Forest-Tundra, Low Shrub-Heath Tundra, and Herbaceous Coastal Tundra Zones crossed by the proposed pipeline route are well known as a result of recent studies in these regions. In addition, there has been considerable testing of species that are natural colonizers of disturbed sites.

The main species suggested for revegetation along the proposed pipeline route are Arctared creeping red fescue and Nugget Kentucky bluegrass, along with the native grasses *Arctagrostis latifolia* (polar grass) and *Calamagrostis canadensis* (bluejoint). These are the best species overall and especially the best in tundra regions. In forested areas additional species become more important. *Arctagrostis latifolia* decreases but *Calamagrostis canadensis* increases in importance. Boreal creeping red fescue can replace Arctared in forested regions.

Reseeding with non-native species should not result in their invasion into undisturbed forest or tundra communities although they do produce viable seed. These introduced species, however, could maintain themselves on disturbed sites in northern locations as documented by Dorogostaiskaya for the U.S.S.R.

The author anticipated that peatlands would be difficult to revegetate, mainly because establishment of plants on organic soils is slower than on mineral soils and because organic soils have lower available nutrients and lower temperatures. Peat surfaces also dry out when they are disturbed and vegetation is removed.

In comparison with natural colonization, the advantage of reseeding is that a seed source is available immediately after disturbance. The major advantage of reseeding appears to be on slopes and unstable sites. Here, it will not prevent erosion but combined with transplants of

Continued ...

Hernandez, H. 1974. Continued

cuttings may help reduce it in time. The replacement of the tundra mat may not prove feasible or useful because ditching in winter may not yield sufficiently large blocks of sod. Success of reseeding will vary from site to site but it is unlikely that cover will be complete on most disturbed sites in the first year. Peatlands, slumps, eroding slopes, ponds and many other areas will have low plant cover. Where cover is high, grazing by animals will occur.

In summary, the author concluded that the most successful varieties to seed are known but they will not provide complete plant cover immediately on all seeded areas.

1. KARLSSON, L.

2. 1973

3. Autecology of cliff and scree plants in Sarek National Park, northern Sweden.

4. Svenska växtgeografiska sällskapet, Box 559, S-751 22 Uppsala, Sweden, Växtekologiska studier 4, 203 p

5. Original

6. a. Sweden; Fennoscandian Highlands

   b. Alpine; Overburden

7. During the summers of 1967 to 1972, the vascular flora on scree and in precipitous sites was studied on three mountains in the eastern part of Sarek National Park.

Below cliff bases in the subalpine zone there is usually a narrow belt of *Betula, Salix, Alnus, Populus* and *Sorbus*. This woody vegetation needs a continuous supply of moisture which it gets from runoff from the cliff face. Below this narrow shrub belt there is usually a more open zone of herbs or grass-dominated heaths. The author distinguished north-facing from south-facing cliffs. These cliff base habitats are one example of naturally occurring habitats that may have some physical or ecological similarities to portions of surface mined lands, in this case the base of a highwall.

Most of this monograph is a detailed description of the ecology and site preferences of individual plant species arranged in order, from those found exclusively in dry sites, to those preferring mesic sites, to those found exclusively in wet places. Many of the listed genera, and even many of the species, also occur in northern Canada.

1. HJELJORD, O.

2. 1971

3. Studier av revegetasjonsforløp i gamle traktorspor på Svalbard. [Studies of re-vegetation in vehicle tracks in Svalbard.]

4. Norsk Polarinstitutt Årbok 1971:31-42

5. Author's abstract

6. a. Svalbard

   b. Arctic Islands; Roads

7. A study was made of vegetation changes and erosion in vehicle tracks in Svalbard. Revegetation appeared to be particularly slow on dry soils. Fifty-year old tracks on *Dryas* heaths were found still to be without significant plant-growth. This is believed to be due to the delayed thawing and the increased soil moisture in the tracks.

   Tracks on wet land appeared, however, to regain their original vegetation rapidly, provided the tracks did not form deep trenches. Severe disturbance of the moss tundra of inland valleys caused the moss to be replaced by a pioneer community consisting of different species of grasses.

   Vehicle tracks on marine clay sediments are believed more likely to cause erosion than tracks on well-drained moraine ridges.

1. HODDER, R.L.
2. 1970
3. Roadside dry-land planting research in Montana.
4. Highway Research Record 335:29-34
5. Original
6. a. Montana; Grasslands

   b. Southern Yukon; Overburden, Roads

7. Two approaches to dry-land planting of adaptable species involves tubelings or plastic-lined planting basins.

The advantage of tubelings, 2 ft long and 2 1/2 inches in diameter, are: (1) roots are placed below the upper dry layer as an undisturbed unit; (2) the long tubes encourage development of narrow but very deep root systems; and (3) the method reduces transplant shock, growth stagnation, the need for irrigation, and extensive maintenance. Tubelings made of rigid jute, reinforced on the outside with high tensile ribbed plastic netting, are effective to contain soil during transport and during the several months of root development. However, they do disintegrate to allow full root development. Pruning of foliage during root development makes transportation easier and reduces foliage load for a limited root system to support. A hardening period of several weeks preceding planting is necessary for acclimatization. Tubelings are planted with a gasoline-powered soil auger. Soil is compacted around the tubeling to ensure soil contact by inserting a tilling shovel repeatedly several inches from the plant.

The second system uses plastic-lined planting basins which condense subsoil moisture and collect it around the plant while preventing soil moisture evaporation. Again pruning is required. On slopes, a low outlet on the downhill rim is required so that precipitation and sediment flushed in can be flushed out; the plant should be on a raised mound in this basin to prevent smothering by sediment. Rocks in the basin low points anchor the liner, and the rims are heeled in to prevent wind disturbance. Clear plastic material lasts only one season before disintegrating; black material is expected to last several seasons and does not weather as readily. Clear plastic appeared to collect more condensation than the black material. Several variables control the quantity of condensate such as proximity and amount of soil moisture reserve, soil texture and colour, size of basin, colour of plastic, temperature differentials, leaks in the plastic seal and distance to bedrock.

1. HODDER, R.L.
2. 1973
3. Surface mined land reclamation research in eastern Montana.
4. In: Selected Papers and Remarks from the Research and Applied Technology Symposium on Mined-Land Reclamation, National Coal Association, Monroeville, Pennsylvania, p 65-74
5. Original
6. a. Montana; Grasslands

   b. Southern Yukon; Overburden

7. Reclamation applicable to Montana is divided into five essential phases: (1) preplanning studies; (2) purpose, design and reclamation plans; (3) development plan, schedule, engineering and shaping; (4) surface manipulation, topsoiling and revegetation; and (5) management. Three alternative approaches are used: (1) plant selection for tolerance to drought, alkalinity and salinity; (2) spoil segregation to bury problematic materials; and (3) topsoiling to cover less desirable soil materials.

Several innovations derived from dryland farming practices show potential, including: (1) condensation traps with plastic lined basins, in which an individual seedling is centrally planted on a mound; (2) supplemental root transplanting using a pair of interconnected seedlings of a rhizomatous shrub, one of which has the crown pruned away leaving two root systems connected to the uncropped seedling; (3) tubelings which are plant seedlings developed in two-ply paper cores or tubes 2 ft long by 2 1/2 inches diameter with reinforced plastic mesh on the outside.

Several water retention systems are being tested. Deep chiseling is a surface treatment that loosens compacted soil to a depth of 6 to 8 inches, creating a series of parallel slots on the spoil surface which impede water flow, increase infiltration and form a cloddy seedbed ideal for broadcast seeding of native seed mixes. Gouging of surface spoils creates surface depressions 10 inches deep, 18 inches across and 25 inches long, amenable to gradual slopes and flood areas. This treatment is very effective in conserving runoff from moderate storms and causing differential snowmelt; a cloddy seedbed is also created which is ideal for broadcast seeding. Dozer basins are large depressions 3 feet deep and 25 feet long placed on a contour at intervals of about 30 feet. Moisture trapped in these basins assures establishment of a nucleus stand of vegetation. A staggered pit configuration will also trap moisture, reduce erosion and aid vegetation establishment.

1. HOLLAND, W.D., S. KOJIMA and G.M. COEN

2. 1974

3. Reclamation planting in Waterton Lakes National Park.

4. Canadian Forestry Service, Northern Forest Research Centre, Edmonton, File Report NOR-972. 23 p

5. Original

6. a. Alberta; Rocky Mountains

   b. Alpine; Overburden, Roads

7. Recommendations for reclamation to a natural state were made for four sites in Waterton Lakes National Park. All sites were considered reclamable and amenable to park use if correct cultural techniques were followed. Recommendations by the authors included:

1. The correct species should be planted in large numbers in proper plantations.

2. Organic matter should be added where feasible and existing organic matter protected with mulch banding (a layer of weed-free peat in a band placed around individual plants to provide protection from competition of grasses).

3. Nitrogen and phosphorus fertilizers (16-20-0 or 11-48-0) are definitely necessary at a rate of 100 to 200 lb/acre/year until establishment and satisfactory growth occur.

4. Scarification is needed for former roadways and parking areas where compacted ground occurs.

5. Correct pruning is necessary to repair damage on existing trees and to reduce the leaf area on transplanted stock.

6. A graduated height succession and design of groupings could assist establishment of new plantings and offset damaging effects of wind. The authors suggested groupings of various indigeneous species that would give successively increasing plant heights, ranging from junipers, to *Symphoricarpos occidentalis, Prunus*, Douglas fir and white spruce.

7. Irrigation is mandatory after planting and supplemental irrigation will be beneficial during the growing season. Late fall irrigation can reduce winter damage to new plantings.

Continued ...

Holland, W.D., S. Kojima and G.M. Coen. 1974. Continued

The authors stressed that density of planting is important because greater numbers of plants afford protection for each other. Even at 100 trees/acre, there is a distance of 20 ft between trees. Allowance must also be made for mortality, damage and continuing maintenance.

1. HOVLAND, D.

2. 1974

3. Revegetation of disturbed soils in Alaska.

4. In: Man's impact on arctic and subarctic environments, Arctic Institute of North America, Montreal, p. 35-37

5. Original

6. a. Alaska; Central Alaska Taiga, Alaskan Tundra

   b. Southern Yukon, Northern Yukon, Yukon Coast; Roads

7. This review of recent revegetation studies in Alaska focuses on the research of K. Van Cleve, Institute of Arctic Biology and W. Mitchell, Institute of Agricultural Sciences, both at the University of Alaska.

A mix of grass species is necessary to achieve the desired objectives of quick growth, complete cover of the soil, abundant growth and contribution to the soil organic layer, winter survival and soil protection. Grasses that most consistently respond favourably to general disturbed soil conditions are: meadow foxtail (*Alopecurus pratensis*), hard sheep fescue (*Festuca ovina* var. *duriuscula*), red fescue (*Festuca rubra*) and Kentucky bluegrass (*Poa pratensis*). Some of the other grasses which have given a favourable response at some sites are: brome grass (*Bromus inermis* x *Bromus pumpellianus*), timothy (*Phleum pratense*) and wheatgrass (*Agropyron* spp.). Results have been less favourable at high altitudes and high latitudes but tentative observations suggest that redtop (*Agrostis alba*) has potential for these areas. Quick surface protection is provided by cereals such as spring or winter rye (*Secale cereale*).

The optimum ratio and rate of fertilizer elements are as yet uncertain, particularly for management of soil fertility for invasion by native plants. At present, the following simple fertilizer program is suggested: (1) at seeding time, apply 50 to 60 lb nitrogen and 60 to 70 lb phosphorus per acre; (2) a second application of 20 lb nitrogen and 30 lb phosphorus per acre is applied the year after seeding. This fertilization could be accomplished by using 500 lb 8-32-16/acre and 50 lb 34-0-0/acre at seeding, followed by 200 lb 8-32-16/acre the following year.

Most plant reactions slow down under cold conditions, including production of growth regulators, ion uptake, release of essential nutrients and microbial decomposition of plant residues. Over time, the nutrient elements become "fixed" in the organic layers of plant residues. Removal of this organic layer seriously influences soil fertility and makes supplemental fertilization necessary to establish vegetation on such sites.

Continued ...

Hovland, D. 1974. Continued

Various examples of damage to terrain are cited from Alaskan experience, including successful revegetation of a road northwest of Livengood where waste material, consisting of organic matter, fine and coarse textured mineral soils and ice, was successfully revegetated. Transplants of native shrubs and trees were utilized with seeded grass in another instance to revegetate a bulldozed trail.

1. JEFFREY, D.W., M. MAYBURY and D. LEVINGE
2. 1975
3. Ecological approach to mining waste revegetation.
4. In: M.J. Jones, Editor, Minerals and the Environment, Institution of Mining and Metallurgy, London, p 371-385
5. Original
6. a. Eire; British Forest

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Tailings

7. Rational procedures are needed for the economic and permanent revegetation of all types of toxic mining waste. Fairly routine procedures for revegetation exist for inert waste but toxic metal wastes are a pressing problem. Up to now, two basic approaches have been used for toxic waste: (1) the technique of burying waste materials and then employing agricultural techniques to maintain plant cover (see Weston, 1973, for how this method was applied to lead and zinc tailings of low toxicity in Ontario); and (2) a method which utilizes plants that are tolerant to heavy metals (Bradshaw 1952;Smith and Bradshaw, 1972). The first method is costly in use of machinery and suitable only in local situations. It requires at least 30 cm of soil, following which the vegetation is managed as required. The second method involves tolerant varieties, mostly grasses, which are very specific and rarely exhibit tolerance to more than one metal. In the authors' research on toxic waste in Ireland, some sites were found to have toxic levels of up to four metals.

The present research objective is to develop a means of economically establishing permanent, virtually maintenance-free vegetation on waste ore dumps and tailings. This implies creation of an ecosystem and the establishment of biological processes such as nitrogen fixation, mineral turnover by decomposer organisms and development of microflora. It will also involve determination of the effects of toxicity on biota.

Several stages are envisaged. The first is site evaluation which is necessary to determine a suitable ecological goal in keeping with the surrounding area. In a second step, sand-culture experiments are conducted to determine the effect on plant growth of copper, zinc and lead sulfides at levels present in the mining waste, and to quantify the relative toxicity of each to legumes and grasses. In the specific examples discussed in this paper, experiments were conducted on *Festuca rubra* ssp. *commuta* and white clover. The addition of as little as 320 ppm Cu resulted in an 80 to 90% reduction in dry weight of both species. The same reduction in growth occurred with 3,000 ppm Pb and

Continued ...

Jeffrey, D.W., M. Maybury and D. Levinge. 1975. Continued

4,000 ppm Zn. Spoil materials can contain levels of all three minerals greatly in excess of these levels (lead may be 10 times the level mentioned), which accentuates the need to reduce the toxic properties of these minerals.

Amelioration of toxicity has been accomplished by topsoil addition (as an insulative layer and for diluting the concentration of heavy metals). Further experiments are in progress testing the ameliorative effect of peat which may be economically feasible on a large scale for conditioning of tailings. Phosphate may also reduce toxicity. In one experiment, increased galena concentrations were matched by increased phosphate and gave normal growth of *Festuca ovina*. It is not known if the interaction of phosphate occurs only with lead or if an antangonism exists with copper and zinc also.

A major requirement is an adequate and stable mineral nutrient regime based on selected species, fertilizer additions, and soil microbial inoculum. Nitrogen poses the greatest problem because it is readily lost through leaching. Legumes offer a practical and economical solution for initial nitrogen build-up and for long-term maintenance. Research is being conducted to find the part of the symbiotic nitrogen-fixing process that is most sensitive to the heavy metal environment; the objective is to select for maximum nitrogen fixation in the presence of heavy metals.

It is also important to achieve an equilibrium between grasses and legumes. Grasses can be established with initial NPK fertilization which is later maintained through nitrogen fixation, plant decay and mineralization. However, legumes are sensitive to fertilizer nitrogen and one study found progressive inhibition of N-fixation with increasing NO_3^- (0 to 300 ppm).

No fungi were isolated from unamended tailings and bacterial isolates, both in number and diversity, were low when compared to natural grassland. With the addition of organic matter substrate and plant cover to the tailings, active fungi increased by 27 times over three winter months with a corresponding bacterial increase.

The authors describe a sample field application of these ideas to an open cast lead and zinc operation in Ireland. A flow chart illustrates the sequence of procedures relevant to an ecologically based revegetation scheme, commencing with design of waste disposal through to additional plantings after grass seeding.

1. JOHNSON, L. and K. VAN CLEVE

2. 1976

3. Revegetation in arctic and subarctic North America. A literature review.

4. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. CRREL Report 76-15. 28 p

5. Original

6. a. Alaska, Yukon, Mackenzie District; Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra, Canadian Tundra, Canadian Taiga
   b. Northwest Territories, Yukon; Overburden, Roads

7. This is a detailed and comprehensive review of revegetation and the biological aspects of restoration research, based on literature from arctic and subarctic North America. Revegetation methods, agronomic grasses and legumes, introduced woody species, native species and succession, herbaceous native species, woody native species and recommendations for research are discussed.

Basic to the revegetation of arctic and subarctic areas are the generally extreme conditions that prevail, the short growing season and the presence of permafrost. The great physical variations in climate, soils, and topography across the vast arctic and subarctic means that no single species or variety can do well under all conditions. Also, the number of species successful for revegetation decreases with increasing latitude. Much of the revegetation research is from the last six years, which means that little long-term information is available.

Revegetation is defined to include re-establishment of a vegetative cover over land disturbed by either natural or man-made causes. Succession after natural disturbance is considered as natural revegetation and for this reason much attention is given to pioneer species that invade disturbed areas. Site characteristics that can be changed by disturbances include soil moisture and density, nutrient status, aeration, temperature, depth of thaw, microrelief, vegetation cover, microflora and other vegetative characteristics. The type of disturbance also affects the revegetation capability, and removal of the seed bed and organic mat leaves a nutrient deficient mineral soil.

The authors point out that the concept of restoration, as opposed to revegetation, is gaining acceptance. Restoration means the return of a site to a physical state comparable to that which existed prior to surface disturbance. Restoration of sites underlain by permafrost would include re-establishment of thermal and hydraulic stability. Restoration

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can be one goal of revegetation but other objectives of revegetation may be control of water-induced erosion, forage production for domestic or wild animals, minimization or prevention of thermokarst, or aesthetic improvement. Prevention of thermal degradation by revegetation may only be applicable in the Subarctic, where new vegetation growth is more rapid. Revegetation does not seem capable of preventing thermokarst in the Arctic, where it may help restore the thermal balance only after several years. The time required for restoration is much longer in the Arctic than in the Subarctic, a difference of perhaps thousands of years. Revegetation can speed restoration by augmenting organic material accumulation, improving nutrient cycles and re-establishing biological functions.

Several factors need consideration in revegetation planning:

1. Favourability of site conditions for germination and seedling survival varies widely and this influences the difficulty of revegetation.

2. Climatic conditions increase in severity from subarctic to low arctic to high arctic regions.

3. The type of substrate after disturbance (organic, gravel, mineral, or mixed subsoil and topsoil) will determine moisture, aeration and nutrient regimes available for plant growth. For example, an organic mat can preserve thermal stability and contain nutrients but when dried there is no moisture and the mat can reduce seed germination. Gravel berms have low moisture retention and may require mulching or other means to increase their water holding capacity as a seedbed.

4. Continuous permafrost in the Arctic and discontinuous permafrost in much of the Subarctic prevents water penetration below the active layer and maintains cold soil temperatures which reduce root growth and nutrient availability.

5. Topographic differences in elevation and gradient, as slight as those on a pipeline berm, can affect site conditions significantly for revegetation planning.

6. Viability of seeds and root stocks in the soil and availability of seed from adjacent areas are important to natural revegetation. Some arctic and subarctic species rely on vegetative reproduction and root stocks in the soil for propagation.

The two most important factors in revegetation are soil nutrient regime and nutrient requirements of plants. Two key aspects of the nutrient regime are the amount of nutrients and the rate of nutrient cycling, and these two factors together determine nutrient availability to plants. Permafrost immobilizes nutrients below the active layer, reduces the total amount of nutrients available and reduces the rate of mineral weathering. The rates of oranic matter decomposition and release of

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nutrient elements such as nitrogen are also reduced by decreases in chemical reaction rates and microbial metabolic rates. Disturbances which remove, bury or mix topsoil with subsoil may thus remove the nutrient capital of the soil.

Low temperatures also seem to inhibit nutrient uptake by plants and low temperatures affect phosphorus metabolism of some native species. Soil texture also is a significant factor because coarse soils do not retain nutrient supplies as well as fine-textured soils. Subarctic muskegs underlain by permafrost are particularly nutrient poor.

Arctic plants have evolved several adaptations, such as cold hardiness in the growing season, winter cold hardiness, growth forms to combat snow abrasion and desiccation, a high ratio of belowground to aboveground biomass, and the use of vegetative reproduction through roots and rhizomes.

A controversial subject in revegetation is the use of native versus introduced species. Based on the literature reviewed the advantages of native species are: (1) seed from native species has shown wide genetic variability; (2) there is no danger of creation of a new "weed" species as there is with introduced species; (3) the phenology of native plants is adapted to the location; (4) native plants are adapted to poor nutrient conditions; and (5) native plants have cold hardiness.

The disadvantages of native species are: (1) slow growth (two native species were found to have slower initial growth than the three best agronomic species); (2) the possibility of disease; (3) native species are poor seed producers; and (4) there is a lack of commercial seed source for native species.

The advantages of introduced species are: (1) the availability of commercial seed supply of most species, permitting almost immediate seeding of large areas; (2) agronomic species have faster initial growth than native species; (3) laboratory and field evaluation of agronomic species has provided information on autecology and response to fertilization which is often lacking for native species; and (4) breeding of introduced species can select for a desired trait suitable for a specific site.

The disadvantages of agronomic species are: (1) their adaptation to optimum nutrient conditions; (2) repeated fertilizer applications may be necessary (vegetation cover was reduced during the third to fifth year in some trial plantings); (3) fertilization may increase susceptibility to winterkill and snowmould; (4) agronomic species appear, from short term results, to decline in cover rating over time; and (5) agronomic species may have an impact on herbivores.

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Johnson, L. and K. Van Cleve. 1976. Continued

Revegetation techniques vary from simple natural revegetation to sophisticated schemes. Two basic handbooks describing techniques are *A Vegetative Guide for Alaska* (1972) and *Alaska Revegetation Workshop Notes* (1973). Several methods have been used and evaluated by various authors. The various techniques include:

1. Seedbed preparation is necessary to optimize temperature, water and microsite conditions. Small differences in seed shape and seedbed characteristics influence germination by altering seed-soil moisture relations. Seedbed preparation increases germination, especially in arctic tundra where extreme conditions prevail.

2. Seeding methods are important for their effect on seed-soil water and temperature relations. Methods of seeding involve drill, hydroseeder or broadcast. Drilling or other methods of covering the seed with soil increases germination rates and decreases the need for high seeding rates.

3. The time of seeding affects germination and over-wintering success. Seedings should be done either early in the growing season or late in the fall.

4. Use of seed mixtures is desirable as this method increases the variability of seed stock for a wide range of conditions and sites by combining the strong points of both arctic adapted and agronomic species. Nurse crops are recommended for arctic sites but are not necessary in much of the Subarctic.

5. Fertilization is the single most important step in revegetation particularly where the organic mat is removed. Nitrogen, phosphorus and potassium increased flowering, cover percent, biomass, plant height and vegetative production at an arctic site. However, fertilization effects are apparently not long lasting, as nutrients become immobilized. All studies recommend fertilizer application, but the recommended rates vary widely and the sites also vary widely in fertility. Most studies recommend application of N, P and K at seeding time, with a repeated application to problem areas.

The first step in revegetation is the selection of varieties to use. Selection is mainly based on the objectives of revegetation (erosion control, browse production, aesthetic enhancement or a combination of these), but is also influenced by several other factors: cold hardiness, reproductive potential, moisture requirements, availability of seed supply, nitrogen fixing capability and growth form. Annuals provide short-term erosion control because of their high shoot production and rapid growth. Long-term control of water-induced erosion is best provided by a large fibrous root system with little top growth. Legume species are selected for their nitrogen-fixing capacity in nitrogen poor soils. Four general criteria of successful species are: reproductive potential (flowering, seed set, rhizomes, bulbils or layering); the ability to survive several growing seasons; root and top biomass production; and rates of plant and groundcover development.

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Johnson, L. and K. Van Cleve. 1976. Continued

Monitoring of species over time is necessary for long-term assessment as infrequent extreme winter or summer temperatures may determine final success. Depending on the revegetation goal, winterkill in the first season need not necessarily be considered a failure because it may provide short-term erosion control or act as a nurse crop. Also varieties which steadily decline after initial establishment can permit natural restoration of a site.

The two best varieties of grass used in the Arctic are Arctared fescue and Nugget bluegrass. Arctared maintains a good cover of 90 to 95% into the third or fourth year. In the Subarctic, creeping red fescue, meadow foxtail, Frontier reed canarygrass, slender weedgrass, Durar hard fescue and Icelandic poa are successful species. Frontier reed canarygrass and slender reedgrass both give a good cover during the first and second year of growth. Legumes tested to date have only limited success north of 65° 20' latitude but do well further south of this line.

Techniques for maintenance of established revegetated areas have not been developed yet because of the recent development of revegetation success. Brush cutting and herbicide treatments may be necessary if herbaceous cover is to be maintained. Repeated fertilizer applications and reseeding may also be necessary, especially in the Arctic where agronomic species tend to decline.

Much of the information about revegetation with native species is derived from studies of natural succession in the Arctic and Subarctic. Successional studies have identified pioneer species, seed dispersal capability, reproductive (sexual and asexual) potential and rates of succession, mostly in general terms. Sites vary markedly in succession rate, but if estimates of succession rates were available, it would be possible for certain management objectives to allow natural succession to occur. A knowledge of chemical and physical changes during succession is valuable to predict levels of fertilization required for certain plant species used in revegetation. From the examples of primary and secondary succession in cases of natural disturbance reported in the literature, several points are made: cyclic succession may occur in areas of severe climate or disturbance because of the recurrent nature of the disturbance (fire, frost, river erosion); a high percentage of plant species have good potential for revegetation of sites disturbed in a manner similar to natural disturbances; and revegetation may only be successful on man-made disturbances which do not exceed the limits of severity of natural disturbances. Revegetation will not occur on unstable sites, but once erosion ceases and thermal stability is re-established, successional trends on all types of sites are similar.

Rates of succession vary particularly for severe sites; one arctic study reported incomplete plant cover after two years and complete cover after 11 years, but restoration of the original vegetation, microtopography and drainage pattern could be in the order of hundreds or thousands of years. Rates of succession in the High Arctic are even lower, with little growth evident after 10 to 20 years.

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Johnson, L. and K. Van Cleve. 1976. Continued

The variable results in secondary succession following disturbance are attributed to differences in ice content of the soil and degree of vegetative cover before the disturbance. Increased thaw depth which makes the soil warmer and makes a greater volume of soil available for root growth and nutrient uptake can favour increased plant growth. Revegetation of subarctic areas can be rapid from the viable rootstock of woody species (willow, aspen and balsam poplar) in the organic mat which is also a favourable seedbed for seeds. Primary invaders of subarctic sites are *Calamagrostis canadensis* and *Corydalis sempervirens*. At a disturbed site on the Alaskan North Slope, pioneer species on mesic sites were tall arctic grass, bluejoint, *Poa arctica* and *Luzula confusa*. On wetter sites *Arctophila fulva*, *Carex aquatilis*, *Senecio congestus* and *Eriophorum scheuchzeri*. The number of pioneer species is greater in the Subarctic and along arctic rivers than on arctic uplands and coastal plains.

Seed increase programs are needed in the Arctic where revegetation species occur naturally. The process of seed production requires time and repeated field testing. At the subarctic research institute at Palmer, Alaska, several species are currently undergoing seed increase: Greenland bluegrass, four varieties of arctic grass, two varieties of red fescue, two varieties of alkaligrass, three varieties of hairgrass and bluejoint reedgrass. Younkin (1973) studied bluejoint and arcticgrass and found that both species produce small amounts of seed compared to other native species, but the seed had high (over 80%) germination rates, little winter kill, and the plants flowered the second year. Little testing has been done with native legumes, but what has been done indicates poor seedling vigour and slow establishment. More work is needed in this area.

Seeding methods with native species parallel those for agronomic species and show a similar need for shallow seed placement. Fertilization for increased growth and coverage is an advantage but not an absolute requirement for native species, except perhaps where the organic mat is removed. The advantage of fertilization is that native species may have increased growth rates and thus stabilize the disturbed site more quickly.

Other techniques with native species include sprigging, coring and sodding. Sprigging is harvesting living rhizomes or stolons (the above-ground creeping stems), cutting them into short segments and planting. This has a higher rate of establishment than seeding and the sprigging material can be gathered over a longer time period than seed. The disadvantages are the bulkier, more delicate material and the special equipment required. This method works well with native species which rely heavily on vegetative reproduction. Coring involves removing a six-inch plug of soils along with native plant material and replanting it on areas to be revegetated. Sodding replaces the organic mat and reduces thermal disturbance. Timing and prevention of drying are important for success.

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Johnson, L. and K. Van Cleve. 1976. Continued

Woody native species offer some unique characteristics for revegetation purposes. They have longer and deeper roots, woody tissue, greater height, and are better adapted for stabilizing slopes, producing browse and creating visual screens. Shrub woody species such as willow and alder can be propagated by cuttings in the Subarctic. Again the timing of planting and substrate moisture are critical. Seeds of birch, alder and spruce seem to offer promise also. Alder is particularly valuable for increasing soil nitrogen. Tests using transplanted white spruce and lodgepole pine seedlings were successful for at least one season in the Subarctic. More information is needed for full evaluation but shrub cuttings hold much promise.

Results using mixtures of native and agronomic species have been generally favourable. Growth of native species is slower for several years but they probably eventually replace agronomic species as the latter decrease over time. The competitive relationships between the two types is not known. It is possible the agronomic species may initially retard the native species and later the better adapted native species may hasten the decline of agronomic species.

The authors indicate that several problems exist with revegetation in the North: (1) revegetation may not achieve everything expected, such as the prevention of thermokarst; (2) goals may conflict; (3) revegetation may create ecological problems; (4) fertilization can cause eutrophication of adjacent water bodies and alter species composition; and (5) grazing of revegetated areas may be a problem or, conversely, stands of foreign grass may alter the behaviour of grazing animals or upset their digestive functions.

Several specific recommendations are made for research:

1. There is a need to identify and quantify the critical parameters for revegetation (nutrient status, moisture holding capacity and soil bulk density, for example) and these should be remeasured for changes during revegetation to permit better understanding of the revegetation process and make extrapolations possible to other sites.

2. Longer term results are needed to predict eventual outcomes of revegetation.

3. More detailed knowledge is needed of the physical, chemical and biological changes accompanying succession, to quantify the time frame for succession, and how to simulate these changes in revegetation methods.

4. More autecological studies of native species that are promising for revegetation work are needed.

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Johnson, L. and K. Van Cleve. 1976. Continued

5. Integrated studies are needed of competition between annual and perennial species, woody and herbaceous species, and agronomic and native species to determine the best mixes of species for particular situations and to aid prediction of the effect of artificial revegetation on long-term restoration.

6. There is a need to determine the optimum field levels of fertilizers and critical nutrients for particular species, the extent of disturbance and response of agronomic and native species to fertilizer, and the similarities or differences between fertilization and changes in nutrients during succession.

7. Other areas of needed research include testing of revegetation for berms, methods for revegetating packed gravel pads, revegetation by mosses (important to the thermal regime), and the relevance of small test plot results for large scale application.

1. JOHNSON, M.S.

2. 1976

3. Plant growth on fluorspar mine tailings.

4. Journal of Soil and Water Conservation 31:17-20

5. Original

6. a. England; British Forest

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. Relatively fine tailings from secondary processing of fluorspar ores in the Peak District of the United Kingdom possess both unfavourable physical and chemical characteristics. The tailings are dominated by particles of fine sand and silt dimension, which are particularly subject to erosion, a situation aggravated by the chemical composition. Older tailings possess much higher calcium fluoride, lead and zinc concentrations. Advances in mineral extraction have reduced the proportion of these minerals in more modern tailings.

Natural revegetation on old tailing sands takes several years. A limited number of species that have evolved populations tolerant of the adverse concentrations of lead and zinc are: red fescue (*Festuca rubra*), vernal sandwort (*Minuartia verna*), and common bentgrass (*Agrostis tenuis*). Naturally established plants on recently produced tailings include, in particular, perennial ryegrass (*Lolium perenne*).

Experimental plantings were made with a mix of perennial ryegrass, red fescue and inoculated white clover in 5:4:1 proportions. The establishing sward responded significantly to phosphorus and nitrogen but not to potassium. Species composition varied according to fertilizer treatments; ryegrass dominated with nitrogen application regardless of phosphorus or potassium treatment. Phosphorus without nitrogen produced a better balance between grasses and clover. Rapid leaching of nutrients was evident the year following planting. Without legumes, regular applications of nitrogen are necessary to maintain productivity and to maintain vegetation that stabilizes the wastes and provides aesthetic cover to the tailings dams.

Vegetation in this study area was unsuitable for livestock because of high flouride, lead and zinc concentrations.

1. JOHNSON, P.L.

2. 1974

3. Moderator's comments

4. In: Man's impact on arctic and subarctic environments, Arctic Institute of North America, Montreal, p. 55-63

5. Original

6. a. Alaska, Yukon, Mackenzie District; Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra, Canadian Tundra, Canadian Taiga
   b. Northwest Territories, Yukon; Overburden,Roads

7. Several concerns are pinpointed regarding revegetation of disturbed areas in the North: the relative importance of native and agronomic species; the introduction of potential weed species; availability of seeds in required quantities; need for fertilization of soils; and growth rates.

Much research has been accomplished in the Arctic and Subarctic of Canada and Alaska. It is apparent that different seed mixes, fertilizer formulations, rates of application and management practices will be required over the length of the proposed Mackenzie Valley gas pipeline. In Alaska, all but two or three of the grasses for revegetation are native species or related to native species. Canadian pipeline-related studies resulted in the selection of three introduced species and two native species. Native species are reported to be invading Canadian and Alaskan test plots that were seeded and fertilized.

Because of slow recycling of minerals, due to the low oxygen potential and low temperature of northern soils, successful revegetation requires the addition of inorganic fertilizers. On the Alaskan North Slope, 400 lb/acre (200 lb/acre at seeding and the same amount 1 year later) of 22-11-11 NPK has been successful. South of the North Slope, applications have been 300 lb/acre and it may be that additional beneficial effects will come from increased phosphorus. Canadian studies report best fertilizer levels are 100 lb elemental nitrogen per acre with either 100 or 200 lb elemental phosphorus per acre applied as ammonium nitrate and phosphate.

1. JONES, D.M., W.W. SHILTS and R.W. WEIN

2. 1976

3. Heavy metal content of tundra plant species.

4. Geological Survey of Canada, Ottawa. Paper 76-1B:273-279

5. Original

6. a. Keewatin District; Canadian Tundra

   b. Mainland Tundra; Overburden, Tailings

7. Certain plant species may be associated with soils that are characterized by high heavy metal levels and some plants preferentially concentrate certain heavy metals. This has implications for mineral prospecting and for animals that harvest these plants.

This study examined the major plant species and peat at seven sites in the central District of Keewatin. Preliminary conclusions are that dwarf birch and dwarf willow species are the most consistent concentrators of zinc, cadmium, uranium, lead and copper, where they grow in close proximity to mineralization. Willow particularly seems to concentrate uranium and cadmium, whereas birch is very rich in zinc. Both of these genera concentrate cobalt to levels that are two or more times those of other plants sampled in this study.

Sedges also reflect copper, lead and zinc mineralization. Very high values were reported for sedge samples at Pitz Lake. The source of the concentration is not known but chemical conditions in the poorly drained terrain around Pitz Lake may have caused preferential concentration of certain elements.

Vetches and *Dryas* also exhibited uranium-concentrating tendencies and might be investigated further.

In a review of work done elsewhere, the authors indicate that Alaskan researchers found several species of mosses and liverworts in association with mineralization. A copper moss, *Mielichhoferia macrocarpa*, was found to have an obligative relationship to Alaskan copper deposits. Researchers in the Yukon Territory and Northwest Territories found dwarf birch and willow to concentrate zinc and copper from underlying sediment or bedrock. A Finnish study identified *Vaccinium vitis-idaea* as a copper concentrator and *Ledum palustre* assimilated abnormal concentrations of copper and molybdenum over mineral deposits. *Ledum palustre* may also be able to synthesize chelating compounds that form complexes with the heavy metal ions, thus rendering them harmless.

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Jones, D.M., W.W. Shilts and R.W. Wein. 1976. Continued

There was a tendency for stable threshold concentrations of some metals in plant tissues in this study, although metal content in the soil or peat varied radically at the different sites. This threshold was most pronounced for silver in the following species: *Betula glandulosa, Empetrum nigrum, Vaccinium vitis-idaea, V. uliginosum, Cassiope tetragona,* vetch species, *Arctostaphylos alpina* and *Calamagrostis* sp. There were pronounced thresholds for cobalt in: *Ledum palustre, Empetrum nigrum, Vaccinium uliginosum, Cassiope tetragona, Rubus chamaemorus, Arctostaphylos alpina,* vetch species and *Calamagrostis* sp.

1. JONES, J.N. Jr., W.H. ARMIGER and G.C. HUNGATE

2. 1973

3. Seed ledges improve stabilization of outer slopes on mine spoil.

4. In: Selected Papers and Remarks from the Research and Applied Technology Symposium on Mined-Land Reclamation, National Coal Association, Monroeville, Pennsylvania, p 125-132

5. Original

6. a. United States; Eastern Forest

   b. Northwest Territories, Yukon; Overburden

7. A series of stairstep terraces were constructed along the contour with hand tools. The terraces were 18 to 24 inches apart and were allowed to come to rest at their natural angle of repose. Larger stones slide further downslope than fine materials so there is a particle size distribution down the slope. Construction of the terraces encouraged water retention that is important for establishing and maintaining a vegetative cover.

In this example from the eastern United States, plants were hand set or direct seeded on the terraces with the necessary fertilizer applications. The improved soil-water relations on the terraces aided rapid plant establishment for soil stabilization and erosion control.

1. KELLER, H. and J-C. LEROY

2. 1975

3. The systematic reclamation of gold mine tailings.

4. Canadian Mining Journal 96:45-46

5. Original

6. a. Ontario, Quebec; Canadian Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Southern Yukon; Tailings

7. Most gold tailings are usually close to normal pH range. The authors have experience in reclamation of gold tailings in the Canadian Shield areas since the late 1960's. Their approach is to greatly accelerate natural revegetation processes, and to induce a complete vegetation cover within weeks using herbaceous perennials on the available waste or tailings material without soil amelioration.

Reclamation procedures follow several steps: 1) heavy and fine grading, particularly of the impounding dam outer slope; 2) ripping all areas where crusts have formed excessively compacted areas; 3) neutralizing, if required, which can be accomplished by two men on a Flextrac Nodwell mounted spreader applying 100 tons crushed limestone/day/machine; 4) raking and harrowing of the tailings and limestone; 5) application of high analysis organic fertilizer at a rate of 1000 lb/acre(which provides mainly nitrogen) and a bacterial population, especially *Rhizobium* from inoculated legumes; 6) mechanical seeding on slopes and flat areas, and hydraulic seeding on steep slopes with mulching if necessary.

A grass and legume mixture develops a dense network of roots that consolidate the tailings with an amazing capacity to regulate precipitation. A vegetative cover can use 500 to 1,000 lbs water to produce one pound of plant matter.

1. KERSHAW, G.P.

2. 1976

3. The periglacial environment and its limitations to development. The Mactung case study, Northwest Territories - Yukon Territory.

4. University of Waterloo, Faculty of Environmental Design, Waterloo, Ontario. M.A. Thesis. 298 p

5. Original

6. a. Mackenzie District, Yukon; Mackenzie Mountains

   b. Alpine; Tailings

7. Various features of the subarctic, alpine environment of the Mactung research area, in the Selwyn Mountains on the Yukon - N.W.T. border are described and discussed as potential limitations to development. Climate, variety in microclimate, permafrost, meso- and micro-landforms, fluvial processes and 30 vegetation communities are outlined in the early chapters of this thesis. Vegetation and geomorphology were considered the two most important features because they result from the interaction of all other components. In a final analysis these two characteristics are used for a landscape description and for evaluation in terms of sensitivity.

Mine tailings will likely have affects on plants through one or more of the following parameters: mortality, vegetation change, successional status, diversity of species, and density of individuals. This could involve one or more of the following processes: photosynthesis, mobilization of assimilates, germination and establishment. Plant communities affected by mine tailings in the Mactung area would be dwarf willow and willow thicket, wet meadow and bogs. The magnitude of this influence is described as severe and the duration long.

Indirect effects of mine tailings could include habitat alteration as a result of changes to one or more of the following: soil bulk density; soil water content; soil atmosphere (microclimate); soil nutrients; and soil biota. Plant communities affected by indirect influence would be dwarf willow and willow thicket, wet meadow and bog.

Similar evaluations are given for solid waste and sewage, the influence of a town and mill, the off-road use of construction equipment, the off-road use of vehicles, increased wild-fire incidence, roads, berms and road grades, construction along water bodies and streams, borrow pits and the camp location.

Continued ...

Kershaw, G.P. 1976. Continued

The geomorphological implications of tailings include increased soil heat flux and permafrost degradation which would affect the depth of active layer; this influence is considered severe in magnitude and of long duration. An added dimension to the problem is the extreme relief of the Mactung area which compounds the environmental disturbance. Particular features of the high relief landscape include blockstreams, gelifluction lobes, thufur (earth hummocks), sorting features, snowbanks and intermittent streams. The amount of material transported in high relief terrain can be substantial and can cause damage to development facilities. However, in the author's opinion, of all the constraints to development, the presence of ground ice is considered the greatest.

A total of 30 vegetation communities are defined and grouped under the following general units; bedrock and barrens; alpine tundra; lichen tundra; heath tundra; dwarf birch; thickets; dwarf willow and willow thickets; krummholz; wet subalpine tundra; wet meadow and bog. One of the communities described is in an area of human disturbance and is composed of *Luzula* spp., *Epilobium angustifolium*, *Epilobium latifolium* and *Stereocaulon* spp. This community is significant since it may be useful in future vegetating of tailings and other disturbed sites.

The disturbed sites represented were located along road cuts and bulldozed swaths made in 1970; they are found on slopes of varying degree and in a wide variety of moisture conditions. On slopes, some of the "new" vegetation is the result of slope processes which transport clumps of vegetation complete with roots and topsoil, similar to a sodding operation. Where bulldozers travelled over an area but did not destroy the vegetation there is fairly rapid recovery, with *Luzula* and *Epilobium* having the greatest cover in these areas.

The author concludes that substrate and microclimate control vegetation distribution at the Mactung study site. Substrate relationships are complex and can vary greatly over a small area.

1. KLEBESADEL, L.J.

2. 1965

3. Response of native bluejoint grass (*Calamagrostis canadensis*) in subarctic Alaska to harvest schedules and fertilizers.

4. Proceedings IX International Grassland Congress:1309-1314

5. Author's summary

6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon; Overburden, Roads

7. Response of native bluejoint grass (*Calamagrostis canadensis*) to 3 schedules of harvest and 5 fertilizer treatments was investigated. Bluejoint harvested twice per season declined markedly in productivity unless phosphorus and potassium were supplied in addition to nitrogen. Sustained yields of 1.0 to 2.5 tons of forage dry matter per acre appear attainable from bluejoint stands annually with proper management. Forage quality was higher with grass harvested once annually just prior to emergence of the inflorescence (boot stage) than at other times the grass was harvested, as indicated by higher crude protein content and lower dry matter content in the grass at boot stage. Low rates of fertilization appeared adequate for maintaining productivity of bluejoint with harvest once annually at boot stage. However, increasing rates of application of complete fertilizers generally increased yields and, in addition, enhanced quality of bluejoint forage by increasing crude protein content and lowering dry matter content of grass harvested.

This study was conducted in the Matanuska Valley in south-central Alaska (61 34 N, 149 00 W).

1. KLEBESADEL, L.J.

2. 1969

3. Agronomic characteristics of the little-known, northern grass, *Arctagrostis latifolia* var. *arundinacea* (Trin.) Griseb., and a proposed common name, tall arcticgrass.

4. Agronomy Journal 61:45-59

5. Original

6. a. Alaska; Central Alaska Taiga, Alaskan Tundra

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon; Overburden, Roads

7. *Arctagrostis latifolia* is a tall-growing, perennial grass, circumpolar in distribution (north of 50° N approximately). It possesses several desirable characteristics for use in the Subarctic: excellent forage yield; extreme winter hardiness; rapid spring growth; and herbage with less dry-matter than other grasses.

The seeds of arcticgrass are very small (5,126,000/kg), necessitating shallow seed placement. Seedling vigour is poor but, once established, the plants have a superior growth rate.

One seed per spikelet is characteristic and seed threshing presented no problems in the trials conducted. Seed matured in the last half of September, somewhat later than timothy and smooth bromegrass.

Limited evidence indicated that this grass tolerates competition poorly during seedling growth. Its performance on various soil types and its response to fertilization require study. The common name, tall arcticgrass, was proposed by the author.

1. KLEBESADEL, L.J.

2. 1969

3. Siberian wildrye (*Elymus sibiricus* L.): agronomic characteristics of a potentially valuable forage and conservation grass for the North.

4. Agronomy Journal 61:855-859

5. Original

6. a. Alaska; Central Alaska Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon; Overburden, Roads

7. Siberian wildrye, a tall-growing perennial bunchgrass native to Europe and Asia, also grows in northwestern Canada and Alaska. In this article, new range extensions are confirmed for the central interior of Alaska.

Evaluation of this subarctic ecotype indicated good seedling vigor, excellent winterhardiness and forage yield potential, and an outstanding seed production capacity. The North American ecotype had marked superiority over the European counterpart for winter hardiness. For Siberian wildrye and other perennial grasses and legumes at this location, there was an inverse relationship between level of winter hardiness and dry-matter production during the seedling year.

Locations where this grass occurs in Alaska receive 25 to 75 cm precipitation annually and most are open and unshaded sites. Wildrye seems to possess a conspicuous ability to grow in infertile, relatively xeric sites such as gravelly road cuts and fills. It spreads rapidly in areas such as this which are often unsuitable to most other plants.

For best seedling vigour Siberian wildrye should be planted less than 5 cm deep; in optimum conditions of silt loam seedbeds planting depth of 1.3 to 2.5 cm is best. This species, plus *Agropyron* species native to Alaska, produce seed in fair abundance even in low-fertility conditions. Wildrye also hybridizes readily with *Agropyron macrourum* to produce *Agroelymus palmerensis*, which because of its parentage should be evaluated for its agronomic potential.

1. KLEBESADEL, L.J.
2. 1970
3. Effects of nitrogen on heading and other components of bromegrass seed yield in the Subarctic.
4. Crop Science 10:639-642
5. Original
6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Polar bromegrass (*Bromus inermis* x *Bromus pumpellianus*) is better adapted to Alaskan climatic conditions than introduced southern varieties of smooth bromegrass. Five rates of nitrogen ranging from 0 to 270 kg/ha were topdressed in spring to a three year-old stand of Polar bromegrass in a subarctic south-central location of Alaska, at the Alaska Agricultural Experiment Station, Palmer (61° 35' N), to determine the influence of nitrogen on seed yield.

In 1964 plots were topdressed in May with ammonium nitrate to supply elemental nitrogen at 0, 45, 90, 180 and 270 kg/ha. In that same year, spikelets of bromegrass per panicle and weight of seed per panicle generally increased with the increasing rates of nitrogen. Increases in spikelets/panicle were not significant at rates above 90 kg N/ha. The number of seeds/spikelet were not affected in 1964, but the seed weight/panicle increased slightly with each increment of nitrogen from 45 to 180 kg/ha. Different rates of nitrogen did not influence the number of panicles/unit area.

In 1965, all plots received 100 kg N/ha in spring. The results that year indicated that the various levels of nitrogen applied in 1964 markedly affected panicles/unit area and seed yields/ha but did not influece seed weight/panicle. The dominant difference among plots in 1965 was the failure of culms in low-nitrogen plots to produce panicles and progressively more culms on plots which had received successively greater applications of nitrogen in 1964.

The results indicated that for subarctic areas late summer nitrogen applications should encourage higher yields of bromegrass seed in the year following application than in the year of application. Spring-applied nitrogen is ineffectual because photoperiods appropriate for the induction of inflorescence (shorter than 13 hr) occur only prior to winter in south-central Alaska. In addition, vegetative growth during the growing season utilizes much of the spring-applied nitrogen with only marginal amounts remaining to influence inflorescence.

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Klebesadel, L.J. 1970. Continued

Further study is needed to determine the optimum time and rate of nitrogen for bromegrass seed production at this latitude. Each increasing rate of nitrogen applied in 1964 resulted in an increase in seed yield in 1965, but it is not known if the maximum response occurred with the 270 kg/ha rate, nor if the optimum rate of nitrogen changes with increasing age of the grass stand as sod becomes more dense. Further investigation should consider the interactions of temperature, photoperiod, and level of nitrogen on tiller formation and on induction of inflorescence in different latitudinally-adapted varieties of bromegrass.

1. KLEBESADEL, L.J.

2. 1970

3. Influence of planting date and latitudinal provenance on winter survival, heading, and seed production of bromegrass and timothy in the Subarctic.

4. Crop Science 10:594-598

5. Original

6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Winter survival, heading, seed yield and forage were compared for latitudinal ecotypes of bromegrass (*Bromus* sp) and timothy (*Phleum pratense*) which were planted in rows at 10-day intervals from 20 May to mid-September, 1964 and 1965 at the Alaska Agricultural Experiment Station, Matanuska (61° 35' N). Previous experimental evidence had indicated that latitudinal adaptation considerably influences heading and seed production of grasses at this subarctic latitude. The four bromegrasses planted were: the Alaska indigenous *Bromus pumpellianus*; Manchar (from the Pacific Northwest); the Alaskan Polar variety; and Achenbach, a Kansas variety. The three timothy varieties planted were Engmo, Climax from Canada and 'Clair' from Kentucky.

The earliest planting date (May 20) resulted in the most heads the following year with all strains. There were progressively fewer heads with later planting dates. *Bromus pumpellianus* and Polar bromegrass produced the highest seed yields of all the grasses, with the former producing more seed than Polar bromegrass for planting dates prior to mid-June. Heading and seed yield declined drastically with planting dates between May and early August and no heads were produced with later planting.

For Engmo timothy, introduced from Norway, different planting dates up to early July had little effect on heading and seed yield the following year, but plantings after this time produced progressively less heading and seed yield.

Winter survival was best with earliest planting dates and poorer with late-season planting. The extent of winter injury was correlated with latitudinal provenance so that Engmo timothy, the two Alaskan bromegrasses (native *Bromus pumpellianus* and Polar bromegrass) and Manchar bromegrass showed excellent winter survival when seeded earlier than mid-July. For late summer planting, *Bromus pumpellianus* and Engmo timothy were the most hardy, with Manchar the poorest and Polar intermediate for winter

Continued ...

Klebesadel, L.J. 1970. Continued

survival. Seeding in late August and September resulted in emergence of seedlings followed by extensive winter kill from frost and virtually no germination the following spring. Those that did germinate were northern-adapted strains.

More evaluation is needed of seeding after mid-September for spring germination. However, soil erosion is a real hazard with such fall seeding as is seed movement by winter winds and spring meltwater.

1. KLEBESADEL, L.J.

2. 1971

3. Native Alaskan legumes studied.

4. Agroborealis 3(1):9-11

5. Original

6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon; Overburden, Roads

7. Legumes are important for two valuable characteristics: high levels of protein, vitamins and minerals (phosphorus and calcium) which make it valuable as forage; and symbiotic assimilation and fixation of nitrogen by bacteria on the legume's roots. There are almost 2,000 legume species in the world of which 40 to 50 are native to Alaska. All of the Alaskan legumes are herbaceous and are found in six genera: *Astragalus, Oxytropis, Lupinus, Vicia, Lathyrus* and *Hedysarum*. They occur in all regions and elevations of Alaska.

Many native legumes are pioneer species which can invade and grow in barren areas. Nitrogen fixation permits legumes to grow in relatively infertile soil materials and various mechanisms, such as winged seed pods, animal-transported seeds, and seeds that pop from the pod with force, give these plants the opportunity of seed invasion. Passage of hard seeds through animal digestive tracts renders the seeds more germinable. The unusually hard seed coat of some legumes, very common in Alaskan legumes, requires scarification or immersion in concentrated sulfuric acid for commercially provided crop species to enhance their germination. Under natural conditions, weathering breaks down the hard seed coat.

Poor seedling vigour and slow establishment have been disadvantages of native legumes, offset partially by planting as early in the season as possible. Native legumes have, however, excelled in field tests of winter hardiness. For example, native legumes adapted to wind-exposed habitat survived well in wind exposed field nurseries, whereas those adapted to woodland or snow-covered sites (protected habitats) did not fare as well but were still better than agricultural varieties of alfalfa, sweet clover or red clover. *Astragalus harringtonii, Astragalus williamsii, Oxytropis foliolosa, Hedysarum mackenzii* and *Hedysarum alpinum americanum* all had a survival rate greater than 64%.

There are no Alaskan data on expected seed yields of native legumes. Most produce seed in fair abundance, except the lupins which are also

Continued ...

Klebesadel, L.J. 1971. Continued

poorly suited for mechanized seed harvest because of the sequential ripening times along the length of each single seed pod.

The potential of native legumes for revegetation is borne out by the broad range of habitats to which they are suited and the occurrence of native legumes as pioneer species. Chemical analysis of herbage and native animal utilization indicated satisfactory forage potential but not to the same level as in agronomic legumes. Native legumes also have poor seedling vigour and regrow poorly after cutting. They also require two to three years after planting to achieve full stature. However, the cultivated legumes lack dependable winter hardiness. The author indicated that research is focussing on which native legumes are best adapted to commercial utilization and the specific opportunities and limitations for their use.

1. KLEBESADEL, L.J.

2. 1971

3. Nyctoperiod modification during late summer and autumn affects winter survival and heading of grasses.

4. Crop Science 11:507-511

5. Original

6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. It is known that latitudinal ecotypes possessing different photoperiodic requirements for growth processes exist within species. Nyctoperiod (duration of diurnal darkness) influenced seedling stature, winter survival and subsequent amount of heading in experiments conducted on cultivars of bromegrass (*Bromus* spp), red fescue (*Festuca rubra*) and Kentucky bluegrass (*Poa pratensis*), using subarctic and mid-temperate varieties.

Lengthened nyctoperiod did not affect height differently than normal nyctoperiod for Polar bromegrass, all bluegrasses and fescues. Shortened nyctoperiods stimulated height growth, while interrupted normal nyctoperiods stimulated the most height growth in all grasses including the native Alaskan bromegrass (*Bromus pumpellianus*), although the latter also grew taller than normal under lengthened nyctoperiod.

The temperate-adapted cultivars sustained greater winter injury in Alaska than did the subarctic ecotypes. Interrupted nyctoperiod stimulated the greatest height growth in autumn and also predisposed plants to the greatest winter injury. Nugget Kentucky bluegrass and Arctared red fescue gave no indication of winter injury when interrupted nyctoperiods were imposed. Both bluegrasses and both red fescues were less affected than the bromegrasses.

A lengthened nyctoperiod improved survival and heading for the temperate-adapted 'Southland' bromegrass but had a deleterious effect on subarctic-adapted *Bromus pumpellianus*. Winter injury and suppressed heading were exhibited by the native northern bromegrass with lengthened nyctoperiod. Exposure to a nyctoperiod of 9 to 15 hours seems to be required for optimum winter survival and panicle production.

1. KLEBESADEL, L.J.
2. 1971
3. Time of planting critical for Alaska grass seed growers.
4. Agroborealis 3(1):14, 26
5. Original
6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon; Overburden, Roads

7. Experimental plantings were conducted in Alaska using four bromegrass species (native Alaskan, Polar variety, Manchar variety and Achenbach variety) and three timothy varieties (Engmo derived from northern Norway, Climax from Canada and Clair from Kentucky). Each grass was planted at 10-day intervals from May 20 to mid-September in two different years.

The results were evaluated by three criteria: winter survival, heading, and seed production. Polar and native bromegrass wintered well and produced the highest seed yields with the earliest planting date. Yields from plantings made June 20 were only half those from the May 20 plantings, and rows planted later than July 20 did not produce seed heads the following year. The Manchar variety survived the winter well but seed production was only one third that of the Polar variety. The Achenbach brome sustained severe winter injury and produced little seed regardless of the planting date.

For the timothy species, Climax sustained severe injury and produced no seed, Clair winterkilled completely and the Engmo timothy survived well with virtually all planting dates. Little effect was experienced for Engmo timothy with any planting date before early July as regards heading out the following year. Seed yields for the first five planting dates between May through to July 8 were about equal; later plantings of Engmo timothy resulted in progressively lower yields.

1. KLEBESADEL, L.J.

2. 1973

3. Photoperiod/nyctoperiod pattern in autumn critical to grasses in Alaska.

4. Agroborealis 5(1):14-15, 29

5. Original

6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon; Overburden, Roads

7. Grasses are like other perennial plants in that they undergo vital physiological processes in response to external environmental stimuli as part of their development of winter hardiness. It was found that the latitudinal difference in the nyctoperiod (duration of nights) and photoperiod (duration of daylight hours) influences the conditioning period of plants which, in turn, influences their winter hardiness. The period of time during which relatively short photoperiods (long nyctoperiods) prevail prior to the onset of winter conditions is very much shorter at subarctic than at mid-temperate latitudes. Three common perennial grasses were chosen for trials: bromegrass, Kentucky bluegrass and red fescue. Within each species, a variety adapted to Alaska and a variety adapted to mid-temperate latitudes was chosen.

The results indicated that different light/dark patterns influenced the growth rate of grasses, with the most striking effect evident in the increased growth when nyctoperiods were interrupted. In these cases, where the nyctoperiod had been interrupted each night for eight weeks prior to freezeup, grasses sustained the most winter injury and some were completely winter-killed. In general the Alaskan-adapted grasses survived best where they were exposed to the normal daily light/dark pattern prior to freezeup. The mid-temperate bromegrass species had poorer winter survival where rows were exposed to normal, subarctic daylight/darkness pattern prior to winter, but had good winter survival and vigorous growth when it was exposed to artifically lengthened (15-hour) daily dark periods for eight weeks before freezeup. These results confirm that plants perform best when exposed to conditions to which they are adapted.

Many grasses native to subarctic and arctic areas form their seed heads in underground tillers during the growing season of the previous year to the one in which they emerge as seed heads. Thus environmental conditions during this formative period can influence seed production. The northern grasses produced most seed heads after exposure to the normal

Continued ...

Klebesadel, L.J. 1973. Continued

daily light/dark pattern to which they were adapted. Lengthened (15-hour) nyctoperiods virtually prevented heading in the native Alaskan bromegrass but favoured the southern adapted varieties. Interrupted nyctoperiods were detrimental to seed head production of all grasses, indicative of the significance of the duration of night to several plant processes and stages of development in the annual cycle.

1. KLEBESADEL, L.J.

2. 1973

3. Grasses and legumes for revegetation in Alaska.

4. In: 1973 Alaska Revegetation Workshop Notes, Cooperative Extension Service, University of Alaska, Publication M7-N-22612, p 16-23

5. Original

6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon; Overburden, Roads

7. Based on several years of work by Alaskan agronomists, this article lists and describes grass and legume species for revegetation purposes. At the time of writing no project solely devoted to revegetation existed, but in the course of work with forage crops the potential utility of using native plant materials for artificial revegetation and soil conservation was explored. The 1972 publication, *A Vegetative Guide for Alaska*, listed preferred grass and legume varieties for use in the various areas of Alaska based on soil type, growing conditions and intended use. The variety of soil and climatic conditions in Alaska means that no single species is suited for all revegetation requirements. Three categories of grasses and legumes are considered for revegetation: (1) varieties developed outside Alaska with seed abundantly available but of widely varying utility in Alaskan conditions; (2) new varieties developed in Alaska, well adapted but with inadequate seed supply; and (3) potentially useful native species with non-existent seed supplies except on experimental plots or localized native stands.

Propagation is simplest and easiest by seed. However, for vegetatively reproduced species which spread by underground rhizomes, "sprigging" is used. This involves chopping rhizomes dug from the ground into small segments, spreading these on a prepared seedbed and discing them into the soil. The chopped segments are perishable and less facile for handling than seeds.

A variety or cultivar of a plant species indicates the identifiable selections of species chosen for a combination of superior characteristics. Such varieties are identified by names such as Polar bromegrass or Nugget Kentucky bluegrass. Such names are important because they come to be associated with important adaptations such as winter hardiness or superiority of the cultivar to a specific geographic area. For example, Engmo timothy from northern Norway is a far more winterhardy species than other varieties of timothy.

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Klebesadel, L.J. 1973. Continued

Several annual and winter-annual grasses are useful for temporary soil stabilization if an area to be revegetated requires stability at a time not in accord with the best early spring planting time of perennial species. A summer planting of an annual can provide erosion control and it can be followed by a perennial cover in the next growing season. Annual ryegrass and winter rye are examples of such annuals which in interior Alaska should be planted before mid-August. No annual legumes are recommended for Alaska.

Perennial grasses have two growth forms: a bunch-type which spreads little and each plant remains a separate clump (timothy and slender wheatgrass); and a sod-forming type which spreads by underground rhizomes and binds the soil better than the bunch-type (bromegrass and Kentucky bluegrass).

The following is a list of grasses found to be winter hardy in tests in south-central Alaska and which are listed by variety in decreasing order of hardiness. In the lists below, a single star after the name indicates that seed supplies are not always adequate at present, a double star indicates that commercial seed supplies are non-existent and seed must be collected from native stands, and a triple star indicates that the species is a poor seed producer and may require vegetative propagation.

SOD-FORMERS

Grass	Latin Name	Varieties
Smooth bromegrass	(Bromus inermis)	Polar*, Carlton, Manchar
Kentucky bluegrass	(Poa pratensis)	Nugget*, Meriod, Park
Red fescue	(Festuca rubra)	Arctared*, Boreal, Olds
Streambank wheatgrass	(Agropyron riparium)	Sodar
Creeping foxtail	(Alopecurus arundinaceus)	Garrison
Quackgrass - considered a serious weed in farm fields	(Agropyron repens)**	(no vars.)
Arctic bromegrass - native Alaskan	(Bromus pumpellianus)	(no vars.)
Beach wildrye - native Alaskan	(Elymus mollis)**	(no vars.)
Salt bluegrass - native Alaskan	(Poa eminens)**	(no vars.)
Sweet holygrass - native Alaskan	(Hierochloe odorata)***	(no vars.)

BUNCH-TYPE

Grass	Latin Name	Varieties
Timothy	(Phleum pratense)	Engmo*
Hard fescue	(Festuca ovina duriuscula)	Durar
Siberian wildrye - native Alaskan	(Elymus sibiricus)**	(no vars.)

Continued ...

Klebesadel, L.J. 1973. Continued

Grass	Latin Name	Varieties
Arctic wheatgrass - native Alaskan	(Agropyron sericeum)**	(no vars.)
Slender wheatgrass - native Alaskan**	(Agropyron trachycaulum)	Revenue
Bluejoint - native Alaskan	(Calamagrostis canadensis)**	(no vars.)
Tall arcticgrass - native Alaskan	(Arctagrostis arundinacea)	(no vars.)

A few marginally winter hardy species commonly considered in Alaska where winter stress is less severe or where snowcover in winter provides insulation includes the following:

SOD-FORMERS

Grass	Latin Name	Varieties
Reed canarygrass	(Phalaris arundinacea)	Frontier
Redtop	(Agrostis alba)	(no vars.)

BUNCH-TYPE

Grass	Latin Name	Varieties
Meadow foxtail	(Alopecurus pratensis)	(no vars.)
Crested wheatgrass	(Agropyron desertorum)	Summit

Legumes are valued for their nitrogen-fixation capacity. Some legumes spread by underground rhizomes (birdvetch) or above-ground stolons (white clover), but some do not spread at all. Some have deep taproots (sweet clover) and some a fibrous root system (alsike clover). Legumes have been of less significance for revegetation than grasses in Alaska but this may change as winter hardy legumes become available. Plant breeding programs at the Institute of Agricultural Sciences, University of Alaska, have developed varieties of superior winter hardiness but seed supply is as yet inadequate.

A list of perennial legumes that have been introduced to Alaska includes:

INTRODUCED LEGUMES

Legume	Latin Name	Varieties
Spreading:		
Birdvetch	(Vicia cracca)	(no vars.)**
White clover	(Trifolium repens)	
Intermediate:		
Alfalfa	(Medicago sativa)	Denali*
Siberian alfalfa	(Medicago falcata)**	(no vars.)

Continued ...

Klebesadel, L.J. 1973. Continued

Legume	Latin Name	Varieties
Non-spreading:		
White sweetclover	(Melilotus alba)***	
Yellow sweetclover	(Melilotus officinalis)***	
Alsike clover	(Trifolium hybridum)	Aurora
Red Clover	(Trifolium pratense)	Alaskland*

Perennial native legumes have a significant role in natural revegetation where they are pioneers that precede other vegetation, stabilize the soils and enhance soil fertility. However, the various native legumes differ considerably in their habitat requirements and care is necessary in selecting them for specific sites. The following is a list of perennial legumes native to Alaska, for which no varieties or commercial seed sources exist:

Lupines:	
Arctic lupine	(Lupinus arcticus)
Nootka lupine	(Lupinus nootkatensis)
Large-leaved lupine	(Lupinus polyphyllus)
Milkvetches:	
American milkvetch	(Astragalus americanus)
Williams milkvetch	(Astragalus williamsii)
Alpine milkvetch	(Astragalus alpinus)
Harringtons milkvetch	(Astragalus harringtonii)
Tanana milkvetch	(Astragalus striatus)
Yukon milkvetch	(Astragalus yukonis)
Sweetvetches:	
Alpine sweetvetch	(Hedysarum alpinum americanum)
Mackenzie sweetvetch	(Hedysarum mackenzii)
Oxytropes:	
Koyukuk	(Oxytropis koyukukensis)
Plains	(Oxytropis campestris)
Wild peas:	
Beach pea	(Lathyrus maritimus)

1. KLEBESADEL, L.J.

2. 1974

3. Winter stresses affecting overwintering crops in the Matanuska Valley.

4. Agroborealis 6(1):17-20

5. Original

6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Winterkill of perennial forage crops in the south-central area of Alaska is due to the severity of winter stress on plants and the degree of plant preparation (physiological and biochemical changes) for winter.

Stress from the external environment results in complete or partial winterkill which may be brought on by one or a combination of factors: extreme temperature oscillation and/or rapid decrease in temperature; ice ponds; the velocity and duration of wind; and the presence or absence of snowcover. The specific causes of winterkill have not yet been determined.

The principal values of snowcover are its insulating capacity, prevention of moisture loss from plants and soil in winter and the moisture released on melting in spring. As an insulator, an 8 inch snow blanket can keep the temperatures at the soil surface near 30° F when air temperatures are as low as -24° F above the snow. Because of this, fields left with stubble or tall perennial growth hold a protective snowcover despite strong winds, which makes the difference between winterkill and the establishment of a new growth the next year.

Ice does not have the same insulative capacity as snow. Ponds of ice from the collection of water in low areas in forage fields resulted in winterkill through smothering. The impervious ice layer acts as a barrier to gaseous diffusion causing toxic accumulation of respiratory compounds in the plants beneath the ice. If stubble (which is hollow) emerges through the ice layer, it provides effective ports for gaseous diffusion and melt initiates earlier immediately surrounding the stubble. Ice crystals in the surface layer of soil can result in frost heaving of seedlings and tap-rooted legumes, a feature more prevalant in clays and silts than in sandy soils.

Strong winds remove protective snow coverings, dehydrate exposed plant tissue, negatively influence the hydrologic balance and contribute to the erosion of wind-dried surface soil.

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Klebesadel, L.J. 1974. Continued

Plants fare best if temperatures remain low and relatively constant during the winter period. Harmful effects occur when long-duration winds remove snow or melt snow which then refreezes as ice sheets or ponds. The degree of exposure has a marked effect on survival. A wind protected alfalfa crop averaged 33% winterkill compared to 90% winterkill for alfalfa in an exposed planting.

More study is needed of the specific causes of winterkill and the interaction of winter's stress factors especially at the microclimate level.

1. KLEBESADEL, L.J.

2. 1974

3. Sweet holygrass, a potentially valuable ally.

4. Agroborealis 6(1):9-10

5. Original

6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Sweet holygrass (*Hierochloe odorata*) has an extensive natural range in Alaska. It is most common in the southern part of the state and becomes more rare in the northern part but is found as far north as 70° N near the arctic coastline. This grass, with two other species found in Alaska, alpine holygrass (*Hierochloe alpina*) and arctic holygrass (*Hierochloe pauciflora*), spreads by underground stems (rhizomes) with amazing rapidity and does not form a central tuft or clump common to other grasses. The foliage is sparse and not particularly dense but this grass is potentially useful for soil stabilization. It possesses the inherent ability to spread rapidly to provide cover for the soil and to bind soil through underground development. Because of the limited height of top growth it would require minimum maintenance. A photograph illustrates a single plant of sweet holygrass transplanted as a 1-inch plug in June 1968 which by July 1969 had spread to a 10 ft^2 cover and which by September 1970 was binding the soil in an area covering more than 50 ft^2.

Sweet holygrass is a poor seed producer and propogation of this species is most successful through vegetative sprigging which involves harvesting living rhizomes or stolons (above-ground creeping stems), cutting these into short segments, and replanting those propagules. Vegetative propogation has several advantages: (1) it circumvents the hazard of seed scattering; (2) harvesting of the vegetative propagules can take place over a longer portion of the growing season; (3) the sprigged segments establish more easily and produce more vigorous new growth than seeds; and (4) sprigs may be disced deeper into the soil than seed to ensure better moisture conditions for early growth.

Disadvantages of vegetative propagation are: (1) the bulkiness of the product that is more susceptible to damage from drying out during handling than is the case with seed; (2) the vegetative sprigs cannot be stored for long periods; (3) transporting the vegetative propagules to

Continued ...

Klebesadel, L.J. 1974. Continued

remote areas and planting on rocky terrain is more difficult than with seed; and (4) specialized equipment is required for vegetative propagation.

In terms of phenology, sweet holygrass is among the earliest of Alaskan grasses with seedheads appearing early in May almost as soon as the grass begins spring growth. Pollen dispersal occurs near the end of May and seed is ripe in late July to early August. The characteristic feature of seedhead formation before winter permits early emergence of the seedheads the following spring and better utilization of the short growing season.

Further studies are underway to determine if the inherent values of sweet holygrass for soil stabilization can be utilized.

1. KLEBESADEL, L.J.

2. 1976

3. Early planting is important to Alaskan growers of bluegrass and red fescue seed.

4. Agroborealis 8(1):22-24

5. Original

6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Planting of Nugget Kentucky bluegrass (*Poa pratensis*) and Arctared red fescue (*Festuca rubra*) on a series of seven dates at about 10-day intervals from late May to early July indicated that these grasses should be planted as early as possible to realize maximum seed yields the following year. Also, the size of individual plants at the beginning of winter was greatly influenced by the different dates of planting; plants from the late May planting were larger and more vigorous, and the most seed heads were produced on plants seeded earliest the previous year. Mean earliest planting date was May 23 at the Alaskan test location.

Growth of these grasses involved development of tillers around the seedling's original crown. The longer the time between seed emergence and growth cessation by killing frost, the more tillers produced by each seedling. Only during the second year do some tillers elongate into stems with seed bearing heads. Seed heads per plant declined markedly with each 10-day delay in planting date.

A previous study found that bromegrass also should be planted as early as possible for maximum seed yield. This 2-year study indicated that planting of subarctic-adapted Polar bromegrass near mid-May resulted in twice as much seed as the same grass planted in early July. However, planting trials with northern-adapted Engmo timothy showed little influence on seed yields for dates varying from May through June, but seed production did decrease with plantings after early July. This points out that different grasses respond differently to a given set of experimental treatments.

Planting grass seed in association with a small-grain companion crop has the advantage of a crop of grain or straw while the grass is establishing, but the competitive effects of a companion crop can limit grass seedling development, and thus reduce grass seed yield the following year.

1. KLEBESADEL, L.J., C.I. BRANTON and J.J. KORANDA
2. 1962
3. Seed characteristics of bluejoint and techniques for threshing.
4. Journal of Range Management 15:227-229
5. Original
6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon; Overburden, Roads

7. *Calamagrostis canadensis* is the most widespread and abundant of the reedgrasses in Alaska. It is extremely winter hardy, spreads by underground rootstocks and readily invades burned over areas as its seeds are easily wind-borne.

Trials reported in this article indicate that bluejoint seed can be satisfactorily threshed and dislodged from floret structures that have copious undesirable callus hairs. Plant materials must be thoroughly dry for maximum effectiveness in processing. Bluejoint seed is extremely small, with a mean of about 3,681,000 seeds/lb.

In one report, successful threshing was achieved by a rasping-bar thresher that had rubber-covered metal bars attached for their full length to the cylinder and to the concave. Mechanical settings for this machine are: cylinder-concave clearance - 0; cylinder speed - 1,480 rpm; tailgate opening - 1/4 inch; and with the fan disconnected.

A second machine, the Ball Hammer mill, Model No. 1. - Modern, which has six hinged hammers, has been used to successfully process seed of several native grasses, including *Calamagrostis* which retains undesirable appendages not removed in normal threshing. For maximum effectiveness the seed must be fed to this machine at full capacity. Mechanical settings for the hammer mill were 1,200 rpm, and a screen with 1/2-inch diameter round holes provided 60% dislodged caryopses and 30% removal of the callus hairs.

Germination tests on threshed caryopses resulted in 60 to 70% germination over a 21-day test period.

1. KLEBESADEL, L.J. and J.C. BRINSMADE

2. 1966

3. Responses of two alfalfas (*Medicago sativa* L. and *Medicago falcata* L.) to time and rate of potassium application in the Subarctic.

4. Agronomy Journal 58:545-549

5. Original

6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. The effects of time and rate of K fertilization on alfalfa were tested at the Alaska Agricultural Experiment Station College Farm near Fairbanks, Alaska. Annual topdressings of 0, 42 and 166 lb K/acre applied in spring or mid-summer were compared for the two alfalfas - *Medicago sativa* var 'Vernal' and *Medicago falcata.*

Stands of both thinned rapidly in the study period from 1959 to 1962 but losses were due primarily to winterkill, especially the 'Vernal' variety, and showed little relationship to K treatment.

However, K treatments resulted in large differences in yield with 166 lb K/acre superior to 42 lb/acre. Crude protein content was little influenced but was lowest with the highest rate of K application. *Medicago falcata* had higher levels of crude protein than 'Vernal'.

The amounts of available K in the soil did not differ among the treatments until the third harvest season, with greatest difference then in plots that received the higher rate of K.

1. KLEBESADEL, L.J. and R.L. TAYLOR

2. 1972

3. New Alaskan grasses excel in winterhardiness.

4. Agroborealis 4(1):9-10

5. Original

6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Grasses adapted to the subarctic climate of Alaska were derived from plant species and ecotypes which flourish locally. Agronomists at the Institute of Agricultural Sciences, Alaska, have worked for the last 15 years to develop grasses that will be useful to the Alaskan area.

The superiority of Alaskan-adapted grasses over species adapted for southern latitudes is evident in the absence of winterkill even in the severe winter of 1970-71. Nugget Kentucky bluegrass and Polar bromegrass are two subarctic-adapted grasses with superior winterhardiness. A species released in Canada in 1963, Redpatch smooth bromegrass, suffered severe winter injury at sample plots during the winter of 1970-71. Winterkilled areas of unadapted turfs are readily subject to weed invasion in the areas of dead grass.

1. KLEBESADEL, L.J. and R.L. TAYLOR
2. 1973
3. Research progress with alfalfa in Alaska.
4. Agroborealis 5(1):18-20
5. Original
6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Poor winter survival has been a strong deterrent to use of alfalfa in Alaska. Trials with various varieties from all areas of the globe showed all of them to lack winter survival adaptation to Alaskan conditions with the exception of Siberian alfalfa (*Medicago falcata*). Despite excellent winter hardiness, this variety still presents problems because there is no commercially available seed source, the species is characterized by low seed yields, establishment is difficult because of poor seedling vigour and it competes poorly with forage grasses.

Attempts at hybridization between the winterhardy Siberian alfalfa and other types produced strains which, although very winterhardy, had the same shortcomings as the Siberian variety.

Other attempts to improve alfalfa for Alaskan conditions included soil amendments. It was found that liming generally improved growth of alfalfa where soils were acidic (usually below pH 5.0) but this amendment had no influence on winter survival, nor had the addition of potassium although heavy applications of the latter did promote better growth and higher forage yields. Different strains of *Rhizobium* bacterial inoculant were tried with no appreciable effect on the crop.

Examination of several old surviving alfalfa plants in the Matanuska Valley, south-central Alaska, showed that invariably the main taproot of each plant was broken off and a shallow root system developed through strong lateral roots. However, experimental severance of the taproot did not have any effect on winter survival.

Surviving alfalfa plants were subsequently transplanted to a special nursery where bees interpollinated the plants that possessed apparent genetic subarctic adaptation. The resulting new strain, called A-syn.B, proved to have superior winterhardiness compared to all other varieties from outside Alaska. Its improved winter survival was due to its superior ability to store high levels of food reserves in the roots prior to winter and to withstand low-temperature stress. Another strain, A-syn. C, also with good winter survival, was derived from a different genetic base. Seed stocks for both of these strains are very small at present and research to improve the strains continues.

1. KLOCK, G.O., A.R. TIEDEMANN and W. LOPUSHINSKY

2. 1975

3. Seeding recommendations for disturbed mountain slopes in north central Washington.

4. United States Department of Agriculture, Forest Service, Portland, Oregon. Research Note PNW-244. 8 p

5. Original

6. a. Washington; Coast Mountains

   b. Southern Yukon; Overburden, Roads

7. Native and introduced plant species were tested for their ability to establish on highly disturbed soils at high elevations varying from 4,100 to 6,560 ft on the east slopes of the Cascade Mountains in north central Washington. Fire lines were constructed by tractors and the same machinery was used in clean-up operations after major forest fires in 1970. Disturbance varied from minimum, with little impact on understory vegetation, to extreme where all vegetation was completely removed.

Immediate post-fire rehabilitation involved seeding and fertilizing 926 acres (375 ha) for erosion control, using seeding rates of 6 to 9 lb/acre. The seed mixture consisted of orchardgrass (*Dactylis glomerata*), hard fescue (*Festuca ovina* var. *duriuscula*), timothy (*Phleum pratense*) and sweet clover (*Melilotus officinalis*). Urea fertilizer was applied at 70 lb/acre (78 kg/ha). Both the seed and fertilizer were broadcast by helicopter. The results of this program showed little seedling emergence and survival in September 1971, particularly at high elevations and on severely disturbed pumice soils.

A study was initiated in 1971 to test the ability of various plants to become established on these firelines. Seeding of 40 species was done on experimental plots in September 1971, using 100 seeds/ft^2 for small seeds and 40 seeds/ft^2 for large seeds. Ammonium phosphate sulfate fertilizer was applied at 300 lb/acre.

After two years, four perennials were satisfactorily established at all locations: orchardgrass, timothy, perennial ryegrass and smooth brome. Their foliage covered greater than 20% of the soil surface whether planted individually or in a mixture. Tall fescue also had good cover but froze out in 1973 at the higher location. The level of success with most species decreased with increasing elevation.

Continued ...

Klock, G.O., A.R. Tiedemann and W. Lopushinsky. 1975. Continued

Cereal rye was the only annual to establish satisfactorily. Its primary value is that it produces considerable dry matter which provides immediate protection for the soil surface, and in subsequent years may improve the soil microclimate. Especially on harsh sites it could aid the establishment of other plants including native species.

The inability of many species to become established at higher elevations results from their susceptibility to damage from frost heaving, cold air and cold soil temperatures, short growing season and high solar radiation levels. The disturbed pumice soils of the area are very coarse textured, making contact between seed and soil difficult with an accompanying low moisture availability. The poor emergence of legumes may be attributed to an absence of micro-organisms because there was no inoculation. The author feels more extensive research on legumes is desirable.

Growth of all species was less satisfactory when seeded as mixtures than when seeded singly, and perennials provided the greatest groundcover in mixed species plots. Fertilization substantially increased emergence, establishment and groundcover. Covering seeds by harrowing or mulching increased the level of success, particularly at higher elevations.

The possible reasons for failure of the initial post-fire seeding are periodic tractor disturbance, a marginal seeding rate, late fall planting time for such an elevation, frost heaving, and seed dispersal over a greater area by the wind drift and air wash of the helicopter.

Planting with native species is much encouraged. However, native species may not spread quickly enough for erosion control and problems exist in seed availability.

1. KLYM, D.J. and C.B. BERRY

2. 1976

3. Reclamation of mined lands, Great Canadian Oil Sands Ltd. lease site, Tar Island, Alberta.

4. In: Proceedings of the Inaugural Meeting Canadian Land Reclamation Association, Crop Science Department, Ontario Agricultural College, University of Guelph, Guelph, Ontario, p. 77-84

5. Original

6. a. Alberta: Canadian Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Tailings

7. The reclamation program of Great Canadian Oil Sands Ltd. is designed for short-term erosion control and long-term establishment of a self-supporting vegetative cover. The oil extraction process creates large quantities of tailings sand contained in dykes and overburden waste dumps. The tailings are fine-textured, have a high pH of 8.0 to 8.5, low nutrient content and poor water-holding capacity. The overburden spoil is generally saline, above neutral in pH, high in clay content, low in organic matter, low in fertility and may contain amounts of oil sands.

Muskeg is added to the overburden and tailings sand as the principal amendment. A four-inch cover of muskeg is incorporated with fertilizer amendment into the sands by a rotovator. Seed was initially hydroseeded but for later plantings the Brillion Grass Seeder was preferred. Overburden waste is disced or harrowed to mix fertilizers and muskeg into the slope surface.

Seed mixes consist of bromegrass, crested wheatgrass, creeping red fescue, slender wheatgrass, sweet clover, Alsike clover and alfalfa. Grasses and legumes were planted together. The grasses formed 50% of the cover by the end of the second season and eventually creeping red fescue became dominant. Cover at the end of the second year was sufficiently dense to control wind and water erosion of tailings sands. Some native species are invading the grasses and there is evidence of volunteer growth of other plant materials believed to be from the muskeg.

Trees and shrubs, planted at 430 trees/acre in a ratio of 2:1 for coniferous to deciduous species, were located in established grass and legume cover with scarification. Seedlings were hand planted and watered. Survival increased as methods improved and adaptable species became available. Lack of moisture and mouse damage have been the major causes of mortality for tree and shrub species.

Continued ...

Klym, D.J. and C.B. Berry. 1976. Continued

The authors suggested that additional knowledge requirements include: 1) the best methods of handling and storing muskeg and the storage effects on muskeg; 2) intensified testing of native species, seed production technology, and handling and establishment of seed supply; 3) means to control surface water runoff on tailings and slopes; and 4) an inventory of muskeg and/or topsoil material for long-range reclamation plans.

The reclamation of 200 acres of tailings dykes and waste dumps, plus planting of 100,000 trees and shrubs, is not considered an unrealistic projection for the next five years.

1. KNABE, W.

2. 1965

3. Observations on world-wide efforts to reclaim industrial waste land.

4. In: G.T. Goodman, R.W. Edwards and J.M. Lambert (Editors), Ecology and the Industrial Society, British Ecological Society Symposium Number 5, John Wiley and Sons, New York, p. 263-296.

5. Original

6. a. World-wide

   b. Northwest Territories, Yukon; Overburden

7. The author summarized studies that have been made on the course of natural revegetation. The first plants that appear on a bare area reveal that there are at least some spots where planting would be successful. The more developed this natural plant colonization, the easier it will be for the plant sociologist to make a reasonable assessment of the site qualities. Even then, conclusions must be drawn carefully because many pioneers are tolerant of a wide range of environmental conditions so that they would not necessarily indicate any particular site properties. In other cases, the pioneers may root in a very shallow layer near the surface only, whereas trees, which need a deeper rooting zone without toxic ingredients, may fail if planted.

Areas where no natural revegetation takes place may be plantable though not suitable for the germination of seed. Therefore, small test plantings with birches, alders or pines may be justified, for however desirable it may be to investigate site qualities before plantings, the practical forester cannot always wait for a scientific survey and assessment of the site.

Very often the factors inhibiting revegetation are immediately apparent from an inspection of the parent material itself, but in other instances a more detailed laboratory study is necessary.

Extreme soil reaction is the factor which most frequently prevents the natural revegetation of industrial waste. Plants are adapted to a limited range of hydrogen ions only, so that pH values below 3.5 and above 8.5 will kill most species. Fortunately these extremes are very rarely found under natural conditions in humid climates, mainly because those ions which are capable of producing such extremes are highly soluble in water and therefore are subject to leaching by rain. This is true of sulphate and chloride anions as well as with the cations sodium and potassium.

Continued ...

Knabe, W. 1965. Continued

The author's review of efforts to reclaim industrial waste land indicated that three different lines of approach can be observed:

(1) Accepting the site conditions as they are after the waste land has been left by industry and planting the area with pioneer plants of low requirements.

(2) Changing bad sites by re-shaping the contours and by adding soil amendments before or after planting.

(3) Planning the future land use before displacing the waste and following this by restoring fertility to the site, which may easily become productive once more.

1. KUC, M.

2. 1972

3. The response of tundra plants to anthropogenic habitats in the High Arctic.

4. Geological Survey of Canada Paper 72-1, Part B:105-112

5. Original

6. a. Queen Elizabeth Islands; Canadian Tundra

   b. Arctic Islands; Overburden, Roads

7. Changes in arctic biota were studied on Melville Island and Cornwallis Island where anthropogenic habitats were mapped and information gathered about native plants which could be useful in rehabilitating disturbed environments at this latitude.

A classification of the interaction between plants and disturbed ground was adapted for the tundra environment and consists of three major categories of which the first two are significant for revegetation:

> 1. Hemerophiles (plants which occupy anthropogenic habitats relatively rapidly and exhibit better-developed life forms than on natural habitats) which are broken down into two sub-groups: (1) luxuriant vascular plants with extensive biomass, strongly developed root systems and greatly increased seed production; and (2) specimens growing better in anthropogenic places. The vascular plants of the first group are *Arctagrostis latifolia, Juncus biglumis, Phippsia algida, Poa abbreviata* and *Puccinellia angustata.* The second group is composed of *Alopecurus alpinus, Cerastium arcticum, Cochlearia officinalis, Deschampsia brevifolia, Dupontia fisheri, Draba bellii, Festuca brachyphylla, Poa alpigena* var. *colpodea, Oxyria digyna, Ranunculus nivalis, Saxifraga cernua* and *Stellaria lactea.*
>
> 2. Hemeradiaphores (plants that appear nearly identical to specimens occurring in natural habitats) such as *Papaver radicatum* and *Potentilla pulchella.*

The hemerophiles and hemeradiaphores listed all seem to be suitable for cultivation under High Arctic conditions. Their expanding root systems impede erosion of the ground on flat or inclined areas and protect soft muddy ground against raindrop bombardment. Their inflorescences abound in well developed seeds. These biological properties characterize plants

Continued ...

Kuc, M. 1972. Continued

which could be utilized for the rehabilitation of bare ground resulting from disturbance.

The third category, hemerophobes, are plants of nearby communities which have not reoccupied their former habitats or which occur as depauperate individuals.

1. LAIDLAW, T.F.

2. 1974

3. The potential of trembling aspen for reclamation planting in Alberta: some techniques of propagation.

4. In: D. Hocking and W.R. MacDonald, Editors, Proceedings of a Workshop on Reclamation of Disturbed Land in Alberta, Northern Forest Research Centre Information Report NOR-X-116, Edmonton, p 88-92

5. Original

6. a. Alberta; Canadian Taiga, Rocky Mountain

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. Trembling aspen (*Populus tremuloides*) has much potential for reclamation because of: (1) wide geographic distributions; (2) vegetative reproduction by suckering; (3) moderate drought tolerance; (4) possible establishment on sandy sites; and (5) natural communities are floristically rich.

The author has successfully tested and used the following technique for propagation of aspen from seed: (1) collect the catkin-bearing twig (female stems) from late-May to mid-June just before dehiscence and dry store the twigs in well-ventilated containers in which the seed erupts as the catkin dries; (2) remove the cotton from the catkins if the seed is to be stored for considerable time or if the seed is used under controlled conditions, using a tumbling technique with a standard nested soil seive and a pneumatic hose or by simply shaking or vibrating the catkins; (3) seed is soaked prior to seeding with a mixture of Captan 50W and garden sulfur and is then surface-sown on a sterile substrate of moist (but not wet) shredded peat moss, fine sand, or a mixture of the two; (4) high humidity is necessary for good germination and should be provided by a fine mist or enclosure of the seedbed by glass or polyethylene with occasional dusting by Captan and sulfur to discourage mildew and damping off; and (5) high light intensities (3,500 ft candles) are necessary for maximal photosynthesis as aspen is shade-intolerant and the high light intensity is desirable for initial seedling establishment if the air temperatures and seedbed temperatures are not excessively high.

In tests by the author, aspen seed had a very high germination rate of 95 to 100%. There is no dormancy-breaking requirement and germination occurs in 48 hr or less after moistening and exposure to light. Healthy

Continued ...

Laidlaw, T.F. 1974. Continued

seeds turn a characteristic light pink colour within a few hours of being moistened.

Under natural conditions germination percentage drops rapidly, but if stored according to the technique developed by Moss (1938) the seed maintains its germination and vigour for at least a year which means that seedlings can therefore be started under controlled conditions at any time of the year. In this technique, seed is stored over $CaCl_2$ crystals in a dessicator at a temperature near 0° C.

Unopened catkins can be sown under certain conditions or sown as cotton and laid directly on the reclamation site where the cotton is valuable as a light-transparent mulch over the delicate seedlings. Aspen can also be propagated vegetatively by root cuttings and young herbaceous stem cuttings derived from root cuttings. However, it is very difficult to root twig cuttings of aspen.

It would be theoretically desirable, by means of the above technique, to artifically clone any genotypes which by virtue of suckering rates, height growth and drought tolerance seem the most suitable for a particular reclamation site. However, the most efficient selection in cloning of aspen for reclamation purposes may well occur naturally on the reclamation site following planting to a wide variety of genetic materials.

1. LAMBERT, J.D.H.

2. 1972

3. Plant succession on tundra mudflows: preliminary observations.

4. Arctic 25:99-106

5. Original

6. a. Mackenzie District; Canadian Tundra

   b. Mackenzie Delta Region, Yukon Coast; Roads

7. Succession on natural silty tundra mudflows, a characteristic feature of arctic slopes with unstable soils, is a two-stage process. The first colonizing phase, of unknown duration, consists of *Senecio congestus, Eriophorum scheuchzeri, Calamagrostis canadensis, Arctagrostis latifolia, Equisetum arvense* and *Petasites frigidus*. The second stage is the re-establishment of the natural community by gradual expansion of clumps of vegetation which persisted during the mudslide and survived as isolated islands of vegetation during the downslope movement of fluid soil.

Seepage from the exposed scar face plus rapid initial thawing of the exposed permafrost are thought to maintain soil saturation and a suitable substrate for pioneer species.

Data on similar past naturally-occurring mudflows would be valuable for information on rates of revegetation, community change, soil nutrient change, build-up of permafrost, decrease in active layer thickness, the soil-binding qualities of successional plants and water-retaining capacities of exposed soil.

1. LAMBERT, J.D.H.

2. 1976

3. Plant succession on an active tundra mud slump, Garry Island, Mackenzie River Delta, Northwest Territories.

4. Canadian Journal of Botany 54:1750-1758

5. Original

6. a. Mackenzie District; Canadian Tundra

   b. Mackenzie Delta Region, Yukon Coast; Roads

7. Three plant associations are identified from an active mud slump on Garry Island in the Mackenzie River Delta, NWT. Such tundra mudflows are characteristic of unstable soils with an abundant but intermittent moisture supply provided by the ice-rich soil of the slump headwall. One particular mud slump was first mapped in 1964 by Kerfoot and in subsequent summers to 1972. Kerfoot had established that the average rate of retreat was 5.1 m/yr with the rate influenced by the composition of the frozen ground. The highest rates of retreat occurred in sections of the headwall with a high ice content. In this study, vegetation transects were set out to determine the sequence and rate of succession.

The three plant associations described represent a time sequence of development. The first association, *Senecio congestus*, was characteristic of early colonization of mud slumps that were covered by a mobile layer of liquid mud. Within this area are isolated hummocks dominated by *Dryas integrifolia, Carex lugens, Salix glauca* and *Vaccinium uliginosum.* These hummocks are created as the exposed ground ice melts and the overlying vegetation layer collapses, with the hummocks remaining as islands. The hummocks are recognizable for up to 4 years but steadily diminish from burial under mud each summer.

The second association was *Arctagrostis latifolia - Senecio congestus* which represents drier conditions below the zone of mobile mud. Some non-flowering *Eriophorum scheuchzeri* occurred in this association.

The third stage of revegetation was the *Arctagrostis latifolia - Eriophorum scheuchzeri* association, which represents further stabilization and drier conditions. Only a few of the hummock-associated species are present here. Revegetation of the bare ground was complete by the ninth year.

Continued ...

Lambert, J.D.H. 1976. Continued

The analysis indicated that an actively receding mud slump may attain 100% cover in less than a decade, with three clear identifiable plant associations. It is not known if this segregation remains clear with increasing age.

Mud slumps initiated by man appear to follow a similar pattern of recession governed by the ratio of ice to mineral soil. Natural revegetation on mud slumps appears to be more rapid than revegetation (natural or artificial) on sites damaged by vehicles. This difference may be nutrient controlled as a result of melting ice at the mud flow scarp face making nutrients more readily available than in disturbances such as seismic lines where flowing water is not common. The author concluded that if native species can establish as rapidly as in this study it is more sensible to allow natural revegetation to follow its own course as man-induced seeding would probably not speed up the process.

Data on annual production and standing dead material indicate that the hummock vegetation makes up the greater percentage of living material in the first two years and then declines; this is followed by an increase in annual production of *Senecio congestus*, which attests to this species' ability to establish and grow in newly disturbed sites. This plant is the initial colonizer and is well adapted to unstable substrate where it has little competition.

Senecio congestus establishes on a water-logged mineral substrate and has a root:shoot ratio of 1.2:3.0, while *Arctagrostis latifolia* requires a mineral soil with free drainage. *Arctagrostis latifolia*, which replaces *Senecio*, has a root:shoot ratio of 1.0:4.1, and *Eriophorum scheuchzeri* has a root:shoot ratio of 1.0:2.1. Root biomass increases with increased stability of the substrate and increased competition for moisture and nutrients. *Senecio* roots penetrate less than 10 cm while those of the other two species have root depths greater than 50 cm.

Senecio congestus and *Eriophorum scheuchzeri* are the only two species not normally found in the dwarf shrub - heath community bordering the mud slump. Literature sources reviewed in the course of this study also indicate the capacity of these species to colonize disturbed areas. Hok (1969) noted that *Senecio congestus* was a prominent colonizer on silty mud outwashes in actively eroding areas of the Alaskan North Slope. Hernandez (1973) reported *Arctagrostis latifolia* to be a major component in man-disturbed areas and *Senecio congestus* was one of the main colonizers of wetter sites at Inuvik, NWT. Younkin (1973) also noted the prominence of *Arctagrostis latifolia* in disturbed areas of the Mackenzie Delta region.

1. LAUGHLIN, W.M.

2. 1962

3. Fertilizer practices for bromegrass.

4. University of Alaska, Alaska Agricultural Experiment Station, Palmer, Alaska. Bulletin 32. 15 p

5. Author's Summary

6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. From 1952 through 1965 replicated experiments employing various experimental designs were conducted on established bromegrass stands to compare several nitrogen carriers, and rates and time of application of nitrogen, phosphorus and potassium.

Ammonium nitrate, ammonium sulfate, and calcium nitrate were equally effective as suppliers of nitrogen to bromegrass. Anhydrous ammonia and calcium cyanamide were inferior to all other nitrogen carriers.

Urea was seldom as effective as ammonium nitrate, ammonium sulfate or calcium nitrate. This was especially true with high nitrogen levels and with fall applications.

Split nitrogen applications (half in the spring and half in early summer) produced higher second and third cutting yields, but no more dry matter for the entire season than did the same amount of nitrogen when applied only in the spring.

Under the conditions of these experiments, bromegrass without irrigation responded economically to nitrogen applications up to 200 lb/acre. The older the stand the greater the nitrogen response.

Spring applications of nitrogen were generally superior to equal quantities applied in the fall.

Bromegrass yields showed little response to phosphorus and potassium applications that exceeded 80 lb P^2O^5 or K^2O/acre.

Fall and spring phosphorus and potassium applications produced essentially equal dry matter yields.

1. LAUGHLIN, W.M.

2. 1973

3. Fertilizers.

4. In: 1973 Alaska Revegetation Workshop Notes, Cooperative Extension Services, University of Alaska, Fairbanks, RP-239, p24-26

5. Original

6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Southern Yukon, Yukon Coast; Overburden, Roads

7. Plants use more nitrogen, phosphorus and potassium than any other nutrients and these elements are usually in short supply in Alaskan soils. Most nitrogen present occurs as organic matter and not in a form available to plants. Legumes that are properly inoculated and provided with adequate nutrients can take nitrogen from the air and convert it to a form useable by other plants.

Other plants can use nitrogen when it is combined with oxygen or hydrogen nitrate or ammonium nitrogen. The nitrogen in soil organic matter is changed to these forms by biological action of soil microorganisms. Nitrate moves easily up and down in the soil with capillary water and can be lost by leaching. The ammonium form is less subject to leaching and not as readily available to plants as the nitrate form.

In Alaska, chemically manufactured fertilizers composed of ammonium nitrate, urea, ammonium phosphate and ammonium polyphosphate are used, the latter two supplying phosphorus as well. Alaskan soils generally contain little available phosphorus and the amounts present are combined with other elements. Analysis of soil samples for reaction and for available nitrate nitrogen, phosphorus and potassium help to determine the proper amounts of fertilizer needed for specific locations and crops.

Secondary elements (calcium, magnesium and sulphur) and the minor elements (copper, boron, zinc, molybdenum, manganese, iron and chlorine) are also used by plants but are generally present in soils in adequate amounts. Some acid soils require calcium as a nutrient and as a means to decrease soil acidity. It is also added to strongly acid soils to increase the availability of other nutrients to growing plants.

1. LAUGHLIN, W.N., P.F. MARTIN and G.R. SMITH
2. 1973
3. Nitrogen fertilization of Polar bromegrass.
4. Agroborealis 5(1):12
5. Original
6. a. Alaska; Southern Alaska Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Field experiments were conducted in the Matanuska Valley, southern Alaska, in 1970 with five rates of nitrogen (0, 100, 150, 200 and 250 lb/acre) using two nitrogen sources (ammonium nitrate and urea) to determine the effect of nitrogen fertilization on total yield, the amount taken up by a crop and the amount recovered from the soil after harvest. Half of the plots received all their nitrogen in spring and half received it in two allotments, one in May and the second after the first harvest in June.

Compared to the single application, the two successive applications of nitrogen increased yield, uptake of nitrogen by the bromegrass and recovery of applied nitrogen. Ammonium nitrate produced greater yields, supplied more nitrogen to the plant and produced greater recovery of applied nitrogen than did urea.

Yields of bromegrass increased with each nitrogen increment as did nitrogen uptake, with the exception of the increase from 150 to 200 lb/acre. The application of more than 150 lb N/acre tended to reduce the recovery of applied nitrogen. Recovery of available nitrogen was not influenced significantly by the time, source or rate of application.

Analyses of soil samples from three depths (2, 4 and 6 inches) showed no measureable downward movement or accumulation of applied fertilizer nutrients. The Matanuska Valley receives low intensity rainfall (8 inches in the growing season) and surface runoff is rare except at snowmelt time. These factors mitigate the downward movement of nutrients.

1. LAWRENCE, D.B., R.E. SCHOENIKE, A. QUISPEL and G. BOND

2. 1967

3. The role of *Dryas drummondii* in vegetation development following ice recession at Glacier Bay, Alaska, with special reference to its nitrogen fixation by root nodules.

4. Journal of Ecology 55:793-813

5. Original

6. a. Alaska; South Coastal

   b. Alpine, Southern Yukon, Northern Yukon; Overburden, Roads

7. *Dryas drummondii* is the first species to obtain dominance on newly deglaciated terrain adjacent to the ice tongue at Glacier Bay, Alaska, and it holds that position for 20 to 40 years. From studies of the role of *Dryas* in vegetation development at Glacier Bay, four functions were outlined: (1) it rapidly stabilized the soil surface against erosion; (2) it increased the amount of soil nitrogen as a result of nitrogen fixation by its root nodules; (3) it aided survival and stimulated growth of woody plants such as cottonwoods and willows that have no symbiotic nitrogen-fixing microorganisms; and (4) it began the development of a humus layer.

Thirty years prior to the date of this article, possibly 35 to 50 km^2 of terrain had been exposed near the head of Glacier Bay. At the time of this study, surfaces nearest the ice were devoid of vascular plants, but older surfaces had scattered pioneers of *Carex, Juncus, Eriophorum*, cottonwoods and willows. Woody species exhibited low vigour, and symtoms of soil nitrogen deficiency. In contrast, the species that developed well on well-drained pioneer surfaces were nodulated plants capable of fixing atmospheric nitrogen, in particular disc-shaped mats of *Dryas drummondii* and less frequently *Dryas drummondii* var. *glandulosa, Dryas integrifolia* and *Dryas octopetala* and on older surfaces further removed from the ice the more rapidly growing alder (*Alnus crispa* ssp *sinuata*).

Dryas is conspicuous on raw sands, gravels and silt-loams of till and outwash and occurs on surfaces more than 10 years and less than 60 years old. It appears to be restricted to calcareous substrate, and grows most luxuriantly on soils with a pH range of 7.8 to 8.5, with low nitrogen, and with a calcium carbonate content of about 5% of the fine earth fraction.

Continued ...

Lawrence, D.B., R.E. Schoenike, A. Quispel and G. Bond. 1967. Continued

In the sequence from the early scattered pioneers closest to the recently deglacierized soil, there occurs a broad belt of *Dryas*, first as scattered discs and then later merging as a solid blanket on ground that is not too wet or too rocky; this *Dryas* zone is followed by a lush alder thicket.

The vigourous growth and fertility of *Dryas* is facilitated by root nodules which fix atmospheric nitrogen and are similar to those of alder except that alder nodules are close to the soil surface and those of *Dryas* are usually 15 cm or more beneath the surface. The nodules of *Dryas* were examined and found to consist of typical metamorphosed roots. The endophyte producing the nodule is found in the cortex central cells. While *Dryas* is in a dominant phase, forming a continuous blanket 30 to 40 years after ice recession, the nitrogen content of the soil-plant system increases from 33 kg/ha up to 400 kg/ha. Trees grow better in areas where *Dryas* is present: a similar growth response was elicited in *Populus* saplings when fertilized with nitrogen.

The *Dryas* mat also influences soil physical and chemical characteristics through the accumulation of organic matter. Bulk density in the fine earth soil fraction at Glacier Bay decreased from 1.50 to 1.37 during the first 35 years of pioneer vegetation. No detectable alteration occurred in the proportion of fine soil particles. Soil acidity increased slightly to 7.7 from 8.0 to 8.4 after an interval of 20 years.

Once the surface is completely covered by vegetation, no more *Dryas* can become established although the mat may thicken. Alder seedlings establish about the same time as *Dryas* but they are fewer in number and may require 20 to 30 years before scattered plants form a thicket dense enough to shade out *Dryas*. The latter is extremely shade sensitive and dies out when covered by leaves or a canopy of alder, willow and/or cottonwood.

The *Dryas* mat stimulates growth in other plants although the stimulation is not as great or as apparent as that for alder. *Dryas* occurs earlier in the successional time scale and grows more slowly than alder. However, its effect is more limited in time and total accumulation of nitrogen is less than for alder. *Dryas* speeds up the rate of succession to a fully developed forest by a period of 20 to 30 years. Also, *Dryas*, because of its wind-dispersed fruits, arrives on new surfaces sooner than alder and provides an erosion-resistant blanket 20 to 30 years before an alder thicket is sufficiently dense for that role. Plants growing in areas stabilized by *Dryas* have a better chance of becoming established.

Once the alder stage in succession is reached, it is more efficient in providing a groundcover, enriching the soil and building up a humus layer faster than *Dryas*. Willows and cottonwood, previously growing in a prostrate form, are stimulated by the nitrogen increment from alder and develop an upright form.

1. LEROY, J-C.

2. 1973

3. How to establish and maintain growth on tailings in Canada - cold winters and short growing seasons.

4. In: C.L. Alpin and G.O. Argall, Jr., Editors, Tailing Disposal Today, Miller Freeman Publications, San Francisco, California, p 411-476.

5. Original

6. a. Ontario, Quebec; Canadian Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mainland Tundra, Southern Yukon; Tailings

7. Effective and economical remedial measures for the reclamation of tailings disposal areas have been successfully employed by Erocon Limited, Toronto, of which the author is a member. This organization specializes in reclamation. The examples given in this article are all from the Precambrian Shield area of Ontario and Quebec.

The basic aim of reclamation is to bring about the immediate establishment of a permanent, self-sustaining, maintenance-free vegetation cover. The basic criteria are: (1) overall amenity of the land surrounding the tailings area; (2) unity in the reclamation scheme and avoidance of piecemeal efforts; (3) selection of species of proven value and adaptation to the environment, with the introduction of new species where it is justified and profitable; and (4) selection of the best use of the reclaimed area, ranging from pastureland, crop land, tree nurseries, sod farms, urban development, recreation or air fields.

Reconversion of the tailings to a useful purpose requires moisture, fertilizers and an adequate bacterial population to promote germination and continued growth. The basic plant combination used involves fast-growing grasses as a nurse crop plus slower growing nitrogen-fixing legumes for a permanent, maintenance-free plant cover. Tailing sands are clean and salt-free, an ideal medium for plant growth when the above elements are added. The homogeneity of the tailings is an advantage for root development.

Typical reclamation steps taken between 45° and 55° N latitude are: (1) heavy and fine grading, particularly on the impounding dam outer slope (a heavy machine can cut a 40° slope 200 ft high at the rate of one acre per day); (2) ripping all areas where iron sulphides have created a hard crust and all areas of excessive compaction such as roads; (3) neutralizing the tailings by spreading calcidic/dolomitic

Continued ...

Leroy, J-C. 1973. Continued

crushed limestone, or using an acidifying compound for alkaline tailings; (4) raking and harrowing to smooth minor irregularities prior to seeding; (5) discing the neutralizing agent into the seedbed and harrowing; (6) fertilizer application, commonly at a rate of 1,000 lb/acre; (7) seeding, which is done by mechanical means using a Brillion-type seeder wherever possible; (8) mulching and artificial membrane spraying to provide a protective layer of inert material which assists germination by creating a suitable microclimate which prevents evaporation; and (9) the use of "hard" seeds in a seeding mix which will take some time to germinate, often not until the next growing season.

Four case studies are offered as examples of Erocon's approach to reclamation. The first is the Hollinger Gold Mine at Timmins, Ontario, where some 56 million tons of tailings waste were left after operation. The completely reclaimed tailings will carry a commercially viable complex consisting of a tree nursery, a sod farm and a cattle farm together with auxilliary service facilities. Three years of preparatory work are required before the nursery is in full-scale operation. For the sod farm, preparation after grading includes fertilization, cultivation and the application of triple super phosphate and herbicide. Liming is not required for the sod farm as grass thrives best on a slightly acid soil. The sod farm will initially cover 40 acres and then be increased to 100 acres at a rate dictated by development of the market and keeping in mind that it takes two years to grow a crop of sod. Birdsfoot trefoil (*Lotus corniculatus*) is used for sod-making as it is a vigorous herbaceous perennial with well developed branching taproots which thrive under particularly difficult climatic and soil conditions. It is also very high in protein and an excellent grazing crop. The sod can be laid by itself in critical areas prone to erosion. Birdsfoot trefoil sod has greater usefulness than common sod because it provides a vegetative cover that controls erosion and permanently stabilizes any slope without extensive maintenance. Birdsfoot trefoil also provides a forage of the highest quality amd is notably free from fungus and insect infestation.

A second example of the usefulness of legumes, and in particular crown vetch, dealt with the open pit slope at the Texas Gulf Kidd Creek Mine near Timmins. This rehabilitation involved the largest crown vetch seeding program in Canada to date. One hundred acres of highly unstable clay slopes were reclaimed where the clay overburden averaged 60 to 80 inches deep in thickness. The sterile clay contained 60% moisture and was devoid of any organic content and bacterial life. It also had a pH close to neutral. The first seeding was too late in the season but the following spring the hards seeds of the seed mix germinated and provided adequate coverage for the second year. A second seeding, conducted in June 1967, gave lush growth but some of these plants winter-killed or were frost-heaved out of the ground. The area established to crown vetch is now densely covered and it is spreading by rhizomes and reseeding. Soil movement has ceased and the ground is appreciably drier because of evapotranspiration by the plants.

Continued ...

Leroy, J-C. 1973. Continued

A third example describes sodding of an area near the Texas Gulf concentrator, east of Timmins, for erosion and dust control. In addition, the 9.5 mile perimeter tailing dam was vegetated with grasses plus legumes, which eliminated all erosion of the outside slope and provided an effective plant cover.

The fourth example is one of vegetating acid tailings which contain a large portion of finely ground sulphide particles, commonly pyrite and pyrrhotite. Enormous quantities of acid effluent can be released by materials during every substantial precipitation, and particularly in the spring thaw. Neutralization of the topmost layer is critical. It is necessary to isolate portions of tailings being reclaimed from the larger area of tailings to prevent heavy flash flooding of acid waters. Ditching of the reclaimed area and precautions to avoid uncontrolled release of acid waters are necessary. Neutralization is accomplished by limestone but there are many variables: composition of the limestone; sizing of the crushed stone; method of application; depth of application; interaction, if any, with fertilizers; and the physical and chemical makeup of the tailings themselves. Uranium tailings at Elliot Lake which contain sulphides were treated with a minimum application of 30 tons of crushed limestone/acre, in the form of high calcium limestone in 1/4 inch screenings, along with 2 tons/acre of a fertilizer high in P and K.

In the Noranda area of Quebec, a supply of limestone was absent and in its place asbestos tailings were substituted to neutralize acid tailings. A grass and legume vegetation cover was established on these tailings.

The author outlines a final example involving very alkaline tailings from Quebec Asbestos Mines These tailings retained considerable amounts of moisture for a long time because of their physical composition. No native vegetation of any kind was observed to volunteer on these tailings even on the older parts. The necessary acidity for these tailings was provided by sulphide tailings from a local base metal mine and with commercial flour sulphur. A rototiller was used to break up the heavily compacted tailing surface and to prepare the seedbed. After application of the neutralizing material, the plots were tilled again to provide some evenness in the spreading and to reduce the lumpiness of the wet sulphide material. The results of the first experimentation indicated that the best overall growth appears linked to the highest rate of application of sulphide tailing material. Good growth occurred with overall sulphide applications of 30 or 40 tons/acre.

In the opinion of the author there is no mine wasteland that cannot be reclaimed systematically and effectively. All areas can be vegetated and in some cases better use can be made of the reclaimed land than in the pre-mining state.

1. LESKO, G.L.

2. 1974

3. Future directions and priorities.

4. In: D. Hocking and W.R. MacDonald, Editors, Proceedings of a Workshop on Reclamation of Disturbed Lands in Alberta, Northern Forest Research Centre, Edmonton, Information Report NOR-X-116, p 209-210.

5. Original

6. a. Alberta; Canadian Taiga, Rocky Mountains

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Tailings

7. Recommendations for research important to successful reclamation of disturbed land in the future include the following suggestions:

1. Research towards the planned land surface after termination of mining operations. Planning the final landforms and surfaces is of utmost importance for best land use afterwards;

2. Research for improved logistics of mining operations and material movements that would place the more valuable materials on the final land surface;

3. Reclamation research into drained tailing ponds which pose a dry-land reclamation problem for tar sand mining;

4. Research related to large-scale production of seeds and cuttings, and methods to induce germination of seeds normally dormant for one or more years after maturation.

1. LESKO, G.L.

2. 1974

3. Preliminary revegetation trials on tar sands tailings at Fort McMurray, Alberta.

4. Northern Forest Research Centre, Edmonton, Alberta. Information Report NOR-X-103. 37 p

5. Original

6. a. Alberta; Canadian Taiga

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. The performance of 29 species of trees, shrubs, herbs and grasses was tested in 11 seed mixtures on 3 surface treatments of a tar sand tailings dike of Great Canadian Oil Sands Company at Fort McMurray, Alberta. Revegetation of the fine, angular to sub-angular quartz sand is considered urgent as the sands are easily eroded by wind and water. These sands are very low in plant nutrients and have a low water-holding capacity also.

All species were hydroseeded after three different soil preparations: (1) contour trenches on a graded surface; (2) a surface packed by a crawler tractor after grading; and (3) grading with no further treatment. In these trials, hydroseeding was made on tailings with no clay or peat amendment.

Better plant cover was achieved by the surface treatment of contour trenches on a graded surface and the surface treatment of packing by crawler tractor. Hydroseeding with no surface treatment after grading failed completely, probably due to a lack of suitable microsites for seed germination.

Grasses alone formed the plant cover. None of the tree species and only a few individual shrubs took root. The successful grasses were *Agropyron cristatum, Agropyron trichophorum, Agropyron latiglume, Agropyron riparium, Bromus inermis, Agrostis alba, Dactylis glomerata* and *Phleum pratense.*

In terms of biomass production, grasses hydroseeded on the contour trenches of a graded surface produced twice as much biomass as grasses under the second treatment (packed surface after grading). The best biomass production of the successful established grasses included *Agropyron cristatum, Agrostis alba, Bromus inermis* and *Dactylis*

Continued ...

Lesko, G.L. 1974. Continued

glomerata. These four species plus *Festuca rubra* and *Agropyron riparium* had the strongest root systems in relation to top growth.

The addition of surface soil, clay or peat to the tailings sand improved seedbed qualities. Well-drained tailings aged for one to two years were not toxic to plants; alkalinity and salinity caused no problem after this exposure.

It is concluded that reclamation on tailing sand should start with grass establishment, followed by the introduction of trees and shrubs when the sand is stabilized and initially improved.

1. LESKO, G.L.

2. 1974

3. Species suitability for sand dune reclamation at Lesser Slave Lake, Alberta.

4. Northern Forest Research Centre, Edmonton, Alberta. Information Report NOR-X-86. 26 p

5. Original

6. a. Alberta; Canadian Taiga

   b. Southwestern Mackenzie; Southern Yukon; Roads

7. Six grass species and one legume were chosen in species suitability experiments for the reclamation of sand dunes in Lesser Slave Lake Provincial Park, Alberta. These were Russian wild rye (*Elymus junceus*), Nordan wheatgrass (*Agropyron desertorum*), pubescent wheatgrass (*Agropyron trichophorum*), Alberta fescue (*Festuca arundinacea*), Fairway wheatgrass (*Agropyron cristatum*), perennial ryegrass (*Lolium perenne*), and sainfoin (*Onobrychis corniculatus*). The first three species are tall perennial grasses.

Sainfoin seemed the only legume suitable for dune reclamation. Sweet clover had good growth in all positions excepting the dune crest, but it exhibited poor germination. The seed of sainfoin is ten times larger than the other tested legumes, which assists resistance to desiccation.

Experiments with saskatoon (*Amelanchier alnifolia*), artemisia, and willow pole cuttings gave good results. Poplar and willow twig cuttings had poor survival, a result related to insufficient moisture.

A recommended procedure for the reclamation of shifting sand areas in north-central Alberta includes:

1. Preparation of topography by rounding of sharp ridges and reducing steep slopes.

2. Control of large-scale sand movement by fences more or less perpendicular to the dominant wind direction. The distance between fences should not be greater than 20 times the height of the fence.

3. Stabilization of the sand with pioneer grasses and forbs. Early spring seeding is recommended to utilize the water supplied by snow melt.

Continued ...

Lesko, G.L. 1974. Continued

4. Hydromulching after seeding to prevent drifting of the seeds.

5. While cuttings or seedlings of drought-tolerant shrubs may be planted at the time of seeding, trees should be introduced only 2 or 3 years after the establishment of protective grass cover. Direct seeding of trees is not recommended. Trees should be planted as large cuttings or at least 2-year-old seedlings in the case of the conifers.

Fertilizer is necessary in the first 2 or 3 years of the revegetation program because the nutrient content of shifting sand is very low.

Before these particular planting trials commenced, the first step in the reclamation of the sand dunes was the mechanical control of sand movement with the help of lath fences which accumulated sand in dunes without entirely stopping sand movement. Further stabilization was achieved by hydromulching which created a thin crust on the surface of the sand. This crust was permeable to water but prevented sand grain movement. The hydromulch crust was effective during at least one growing season but had a tendency to break up under foot traffic. If seeds are already in the ground, hydromulch improves the germination of these seeds by conserving moisture. On the Lesser Slave Lake dunes, Russian thistle had invaded the dunes before hydromulching. Although this plant did not endure into the second growing season, it provided valuable shelter for young grass seedlings sown before hydromulching. The combined cover of seeded and volunteer plants made a graphic contrast to the same area before seeding.

1. LESKO, G.L., H.M. ETTER and T.M. DILLON

2. 1975

3. Species selection, seedling establishment and early growth on coal mine spoils at Luscar, Alberta.

4. Northern Forest Research Centre, Canadian Forestry Service, Edmonton, Alberta. Information Report NOR-X-117. 37 p

5. Original

6. a. Alberta; Rocky Mountains

   b. Alpine; Overburden

7. Trial seeding of 32 species including grasses, herbs, shrubs and trees was carried out by hydroseeding at two coal mine sites at Luscar in west-central Alberta (53 00 N, 117 30 W). Seeding took place between elevations 1,650 and 1,680 m on weathered sandstone and shale spoil, undisturbed for 20 years, and on which little natural vegetation had established.

Germination and seedling establishment were concentrated in depressional microsites on both rough-graded and bulldozer-packed surfaces. More microsites were created by rough-grading. The advantages of bulldozer packing were marginal. Establishment of grasses by the hydroseeding method proved more successful than for legumes and other herbs.

Spring seeding gave better results than fall seeding. This was especially true for the legumes *Medicago* and *Melilotus* on all slope gradients except the steepest which had an adverse effect on both types of seeds.

Available seedbed moisture seems to be the most important factor influencing germination and establishment. Depressional microsites provided a more favourable moisture regime and thus a better seedbed. Soil surface temperatures were approximately 5° C cooler in the depressional microsites than adjacent non-depressional areas on warm sunny days but at no time did temperatures reach lethal levels (55 to 60° C). Soil surface temperature did not prove to be a limiting factor in plant establishment.

Seedling establishment on steep slopes was hindered by wind and water erosion and movement of soil particles downslope. Droughtiness of some slopes, particularly upper portions, also prevented successful germination.

Continued ...

Lesko, G.L., H.M. Etter and T.M. Dillon. 1975. Continued

A hydromulch of wood fibers and adhesive would increase soil stability and plant establishment on steeper slopes but was considered unnecessary on moderate slopes.

The effect of slope on seeding success was more pronounced than seeding time. Establishment rates of seedlings decreased from 100 plants/m^2 at 0% slope to 10 plants/m^2 at 70% slope, with the greatest drop in the range from 0 to 20%. A 50% slope was regarded as a realistic upper slope limit, at which approximately 30 seedlings/m^2 could establish.

In general, the grasses were more successful on the spoils than the legumes. Seed mix 3 consisting of *Agropyron riparium*, *Poa pratensis* and *Rosa woodsii* had the largest number of established plants/m^2 and was superior to all other mixtures in the 1973 planting. *Agrostis alba*, *Medicago sativa*, *Lupinus* sp., *Koeleria cristata*, *Phacelia sericea* and *Linaria dalmatica* gave the lowest plant densities in trials.

Native species did not appear to have an advantage over introduced species in the first two growing seasons after seeding. In summary, the number of native and introduced grasses and herbs seeded was approximately equal with equal survival at one location and slightly more introduced species surviving at a second location.

Direct seeding of woody species was a failure and it is recommended that this practice be avoided. Of ten woody species planted, only *Elaeagnus commutata* had limited success.

1. LIMSTROM, G.A.

2. 1952

3. Effects of grading strip-mined lands on the early survival and growth of planted trees.

4. U.S. Department of Agriculture, Forest Service, Central States Forest Experiment Station, Columbus, Ohio. Technical Paper 130. 35 p

5. Original

6. a. Ohio, Illinois, Kansas; Eastern Forest

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. The productivity of strip-mined lands varies with their fertility and physical and chemical characteristics. Unlike soils, such lands are not as uniform in composition over large areas, and may show great variability in small areas.

Most reclamation programs and legislation require that strip-mined lands be graded to a level or gently rolling topography. Based on the literature reviewed, this practice is brought into question. An experiment was established to examine the survival of a variety of trees, 3 to 5 years after planting, on graded and ungraded mined land. The experimental plantings were supplemented with studies of moisture conditions and other site factors which could account for the survival differences. Four experimental plantings were made on widely varying sites in Ohio, Illinois and Kansas.

The results indicated that graded banks dried more rapidly during periods of drought than ungraded banks because the graded banks could not absorb what little rain occurred. When excess rain occurred, the same graded banks became saturated and water-logged because of lower percolation rates brought about by compaction of the surface materials.

In general, survival was better on ungraded slopes. Overall survival at the end of the first year was 68% and 74% for graded and ungraded plantings: after the third year survival was 55% and 69%, respectively. Differences in height growth were not as pronounced as differences in survival.

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Limstrom, G.A. 1952. Continued

The extent of the harmful effects of grading on early development of planted trees varies with the texture and plasticity of bank materials, climatic conditions, special moisture conditions as influenced by aspect and topographic position, and species planted. Drought is the limiting factor for survival, whereas water-logging and saturation have a significant harmful effect on growth.

Careful evaluation of site and climatic conditions is necessary on each parcel of strip-mined land before there is a decision to grade. Texture and the plasticity of the clay fraction are important. Quartz and feldspar are non-plastic, whereas kaolinite, talc, muscovite and biotite with platy or sheet-like structure are plastic; the proportions of such minerals in the banks are important considerations. A rough field test involves digging a hole 10 or 12 inches deep; if the soil particles cling to the shale or other stones or are in any way "cloddy", the material will likely compact after grading.

Although the species utilized in this experiment were adapted to temperate conditions, they were distinguished according to their tolerance to compacted conditions. Tolerant species listed in decreasing rank were black locust, green ash, white ash, eastern red cedar, sweet gum, black cherry, shortleaf pine, Virginia pine, loblolly pine, bur oak, sycamore, pitch pine, jack pine, yellow poplar and white pine.

Some of the advantages of grading are: lands are more accessible; it simplifies and could lower the cost of maintenance and harvesting of crops; it may improve the appearance of the landscape especially in the initial years; and it can improve lands for pasture and cultivated crops. The main disadvantages are associated with compaction, especially since tree planting is more difficult on compacted ground. Grading banks when they are dry can minimize compaction but it is not a real solution.

An unknown factor is whether the trends established in this experiment will endure over time. Based on a study in England (Whyte and Sisam 1949), better development of trees occurred on ungraded banks than on graded banks, from observations 50 years after planting.

1. LOTSPEICH, F.B.

2. 1971

3. Environmental guidelines for road construction in Alaska.

4. Environmental Protection Agency, Alaska Water Laboratory, College, Alaska. Report 1610 G01 09/71. 127 p

5. Original

6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra

   b. Northwest Territories, Yukon; Roads

7. This report compiles and describes the best measures required to give environmental protection during road construction under cold climate conditions.

In relation to vegetation, the author recommended that construction should leave all the vegetative mat possible on the edge of any cut resulting from earth works. The mat is effective in protecting the upper 4 to 6 inches of the cut as melting causes the cut to recede. Any thawed soil shifting down the toe of the cut protects the lower part and helps to retard the melting rate and permits meltwater to drop sediment and run clear.

Vegetation, overburden and other materials removed from surfaces should be disposed of in an approved manner. Chipped vegetative debris should be spread evenly over the slopes with other organic material and topsoil. Slopes should be vegetated by seeding and planting with suitable plant materials. Seeding in the snow is one possibility if feasible to take advantage of early moisture for seed germination. All disturbed areas must be left in a stabilized condition by seeding, planting, mulching and the placement of mat binders, soil binders, rock or gravel blankets, or other structures to stabilize the site. Seeding and planting should be accomplished as early as possible in the first growing season following disturbance and should be repeated if unsuccessful on the first attempt. All other restoration should be completed as soon as possible following completion of the project.

The main theme throughout this text is that planning and good design can reduce the incidence of erosion, reduce pollution potential and minimize costly maintenance. Some maintenance must continue as long as the road is being used and these costs can be reduced if the route is properly selected and problem areas correctly handled during design. Guidelines for maintenance include a scheduled maintenance plan on a continuous basis, to keep all cuts and fills subject to erosion covered with vegetation or some other stabilizing material, use of fertilizers and use of chemical stabilizers where natural fertility is low to give vegetation a chance for more rapid growth.

1. LOWENBERGER, F.J.

2. 1973

3. Reclamation of strip mined overburden through tree planting.

4. University of British Columbia, Vancouver, B.C. M.F. Thesis. 117 p

5. Original

6. a. British Columbia; Rocky Mountains

   b. Alpine; Overburden

7. The results of field plantings, part of the revegetation program of mined sites associated with the Kaiser Resources Limited surface coal mining near Michel and Natal in southeast British Columbia, indicate that trees are suitable for use in revegetation at these low and high elevation sites. Ten plots were established at elevations between 3,700 and 4,900 ft on abandoned wastes of old mines and an eleventh plot was located at 6,800 ft at a new mine site on Harmer Ridge.

Both spring and fall plantings were tried and for all tree species spring planting survival proved much higher (38%) than fall planting (25%). Winterkill, frostheave, planting shock, and exposure to extreme elements before snowfall, caused the poor survival rates with fall planting. Spring weather was cool and wet, amenable to successful planting, whereas fall weather was predominantly warm and dry. Future plans should be developed for spring planting to avoid the need for replanting.

Trees grown in organic soil plug containers showed better survival and growth than bare-root seedlings or stock grown in plastic bullets. Root development was best in bare-root and organic soil plug stock. Optimum age of planting was two years and optimum size was 8 to 12 inches, especially for sites with black, hot surfaces or steep, unconsolidated slopes where seedlings were buried by sluffing. Age, size and hardiness of seedlings all affect survival and long-term reclamation success.

Lodgepole pine was the best species for planting for the elevation range 3,500 to 5,000 ft. It is capable of colonizing severe sites, including the black coal residues. Lodgepole pine can also tolerate browsing; it was the heaviest browsed and fastest growing of the species tried in the study. Douglas fir was not suited to heated surfaces of slope material. Spruce had good survival at the high elevation site and was well suited to that elevation. Other conifers and broadleaved trees indigenous to the area for planting alternatives not included in the test plots were aspen (*Populus tremuloides*), western larch (*Larix occidentalis*) and alpine fir (*Abies lasiocarpa*).

Continued ...

Lowenberger, F.J. 1973. Continued

High seedling mortality occurred on compacted sites and south-facing slopes. Shrubs and grass are preferred for the drier south-facing slopes where few trees grow naturally. The problem of compaction could be overcome by such pre-planting preparation as deep ploughing or ripping.

Browsing was heaviest for lodgepole pine and in decreasing amounts affected Douglas fir and Engelmann spruce. It is important for seedling survival that browsing be minimal and for this reason the author recommended that a less-favoured browse species, such as Engelmann spruce, be planted.

Water erosion and sluffing on steep slopes were the two types of erosion which destroyed 2% of the planted seedlings. Sluffing occurred on slopes of 30% or more. The cumulative effects of erosion damage within the established plots is expected to be serious. Extensive and well planned drainage systems are needed to minimize water erosion and terracing of the steeper slopes is needed to check water erosion and sluffing. Where slopes exceed 30%, terracing by itself will not check earth movement. Sluffing on steep slopes only a few feet long resulted in partial burial of seedlings. Chemical additives such as elastomeric polymer or lignosulfonate provided good stabilization in this study and offer some solution.

1. McCOWN, B.H.

2. 1973

3. Growth and survival of northern plants at low soil temperatures. Growth response, organic nutrients and ammonium utilization.

4. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. Special Report 186. 15 p

5. Author's abstract with additions

6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra

   b. Northwest Territories, Yukon; Overburden, Roads, Tailings

7. Low soil temperatures have been implicated as one of the limiting factors for plant growth in northern regions and may be responsible for the failure of some revegetation attempts in such areas. Because of the importance of maintaining an adequate plant cover over ice-rich arctic and subarctic soils, laboratory experiments were performed to further clarify the influence of soil temperature on plant growth. At two soil temperatures (5° and 15°C) and with three levels of soil ammonium, data were obtained that showed that low soil temperatures can be extremely inhibitory for the growth of introduced graminoid revegetation species. In contrast to the adapted native arctic grasses, introduced species were not able to utilize increased soil nutrient levels at 5°C. No significant influence of soil temperature on the organic nutrient content of the plants was observed. High levels of organic nutrients were found in both adapted and unadapted species, indicating that this factor may not be a specific adaptation to northern regions. It is suggested that species intended for revegetation purposes in northern regions be screened for tolerance to low soil temperature utilizing such relatively rapid laboratory techniques.

One paragraph of this report emphasizes the particular importance of the inability of unadapted species to utilize soil nutrients in cold soils, which indicates that revegetation using such species cannot be stimulated by fertilization. However, fertilization may be an effective way of stimulating adapted species which are capable of capitalizing on increased soil nutrient levels in cold soils.

1. McCOY, D.

2. 1975

3. Tent Mountain reclamation site. Some analyses of materials used to prepare the base.

4. Alberta Environmental Protection Services, Earth Sciences and Licensing Division, Technical Development Branch, Edmonton. 10 p

5. Original

6. a. Alberta; Rocky Mountains

   b. Alpine; Overburden

7. The Coleman Collieries reclamation site on Tent Mountain is approximately 10 acres on a north-facing 25° slope at an elevation of 7,000 ft a.s.l. Base material is overburden from the strip mining of coal, with reserved topsoil intended to be spread over the reclaimed site.

Chemical and physical analyses of base material from Tent Mountain indicate that an average 18% of material by weight is less than 2 mm diameter which is considered to be soil-sized material. Particle size distribution is important as smaller particles are chemically more reactive and should provide good rooting media for plants. Many larger pieces are expected to break down from physical and chemical weathering, adding to the smaller fractions.

Total nitrogen content was high but not readily available to plants except over the long term. A readily available form must be applied. Nitrate concentrations were found to be very low and an external source of about 100 lb/acre of nitrogen is required. Extractable phosphorus averaged 10 mg/kg, indicating that the base material could supply the phosphorus required for plant growth, although there may be a need for an additional 30 lb/acre of phosphorus.

The materials are non-saline and non-sodic. The pH values ranged from slightly alkaline to slightly acidic, an ideal range for most agricultural crops. Cation exchange capacity was 7.0 and 5.7 me/100 g for fractions a and b. External application of soil, peat or sewage sludge is recommended to increase the cation exchange capacity, which should also increase retention of fertilizers.

1. McDONALD, J.D.

2. 1977

3. Reclamation planning for British Columbia Peace River Coal Block.

4. Paper presented to the Coal Industry Reclamation Symposium, Banff Springs Hotel, February 13-17, 1977, sponsored by The Coal Association of Canada. 19 p. plus appendices

5. Original

6. a. British Columbia; Rocky Mountains

   b. Alpine; Overburden, Roads, Tailings

7. In the Peace River Coal Block, revegetation is considered an essential step on waste dumps (spoil piles), on completed tailings ponds, on coal reject dumps, on all slopes along roads, and on areas around plant sites.

On the mines operated by Quintette Coal Ltd. (90% alpine, 10% forested), field trials of surface revegetation of disturbed areas were established in 1976. Of the grasses, creeping red fescue, bromegrass, meadow foxtail, meadow fescue, timothy and red top showed promising growth, while slender wheatgrass and Canada bluegrass did not perform well. Legumes require two seasons to become well established, so there are still low cover values for the 1976 trials.

Seed mixes already in use in the Peace River Coal Block include:

	Forested Regions		Alpine Regions
Mix #1	creeping red fescue Climax timothy alsike clover	Mix #1	creeping red fescue Climax timothy alsike clover
Mix #2	creeping red fescue Climax timothy crested wheatgrass brome grass alsike clover	Mix #2	creeping red fescue Climax timothy crested wheatgrass Kentucky bluegrass crown vetch creeping red fescue
Mix #3	creeping red fescue alsike clover	Mix #3	Kentucky bluegrass wildrye grass alsike clover

Continued ...

McDonald, J.D. 1977. Continued

Varieties that are being evaluated on test plots in the Peace River Coal Block include: Beaver alfalfa, Dawn alsike clover, Melrose sainfoin, Altaswede red clover, Nora white clover, Leo birdsfoot trefoil, Oasis chewings fescue, Fairway crested wheatgrass, Biljant hard fescue, Mimer meadow fescue, Revenue slender wheatgrass, Boreal creeping red fescue, Greenleaf pubescent wheatgrass, Climax timothy, Sodar streambank wheatgrass, Carlton brome grass, Chief intermediate wheatgrass, Magna bromegrass, Park Kentucky bluegrass, Oregon Common meadow foxtail, Castor reed canarygrass, Exeter colonial bentgrass and Sawki Russian wildrye.

Costs of reclaiming disturbed land can vary from $100/acre under ideal conditions to as much as $5,000/acre. The author summarized general reclamation costs as follows: Site preparation (resloping, replacement of overburden and topsoil, and agricultural treatment) - $125/hectare to $12,500/hectare; Revegetation - cost of seed and fertilizers $250 to $500/hectare, hydroseeding with mulch $375/hectare plus at least $250/hectare for seed and mulch, and for tree planting $300 to $500/acre.

The author stressed that reclamation will be difficult in the Peace River Coal Block because of the high altitude of disturbed areas. However, work in the Kootenay Coal Block and at McIntyre Mines at Grand Cache, Alberta, has demonstrated that high altitude revegetation can be done. The author recommended the establishment of one central nursery to be operated jointly by several companies, along with early research into the use of native alpine species that have already adapted to the short growing season of the high altitude areas.

1. MacLEAN, A.J. and A.J. DEKKER

2. 1976

3. Lime requirement and availability of nutrients and toxic metals to plants grown in acid mine tailings.

4. Canadian Journal of Soil Science 56:27-36

5. Portions of authors' abstract with additions

6. a. New Brunswick, Ontario, Quebec; Canadian Taiga

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. Vegetation trials were conducted on six acid pyrite-bearing mine tailings samples [from Quemont (2 samples), Waite Amulet (Noranda), and Elliot Lake fine, Elliot Lake coarse, and Heath Steele (New Brunswick)], varying in pH from 1.9 to 2.9. Reed canarygrass was grown successfully in the limed and fertilized tailings except in an unweathered sample containing a relatively high amount of sulphur. In most instances, the composition of the plants did not vary greatly from that reported for plants grown in soil, although the concentrations of sulphur tended to be high. In this and another experiment with buckwheat, a soil layer on top of the tailings was used with varying effectiveness in establishing vegetation. With inadequate lime, the soil became very acid and released relatively high amounts of Mn, Fe and Al to the plants. The tailings do not have the buffering capacity of soil, so that a relatively small decrease in the amount of lime used may reduce its effectiveness markedly.

Leaching of the tailings with water was effective in removing considerable acid and increased the pH of tailings by a minimum of 1 pH unit. Periodic leaching of the acid formed during weathering should reduce the lime requirement for establishing vegetation.

Species differences in the rate of metal uptake may explain why the concentrations of metals in reed canarygrass were not excessive despite the extremely acid reaction of one tailing in particular. In the reed canarygrass test, heavy metals presented no problem when sufficient lime was added. Based on this study, it is not likely that a shallow soil layer would have any long-term effectiveness in maintaining vegetation on inadequately limed acid tailings, but it could be an effective medium for germination of seed and initial growth in tailings prone to crusting.

1. MACYK, T.M.

2. 1974

3. Reclamation research direction and priorities.

4. In: D. Hocking and W.R. MacDonald, Editors, Proceedings of a Workshop on reclamation of disturbed lands in Alberta, Northern Forest Research Centre, Edmonton, Information Report NOR-X-116, p 211-213

5. Original

6. a. Alberta; Rocky Mountains

   b. Alpine; Overburden, Roads

7. Four priorities that the author felt necessary in reclamation research are listed:

   1. Cooperation between government and industry to provide an adequate supply of suitable seed and planting stock for revegetation purposes is a key requirement.

   2. Development of a suitable, economically feasible method of establishing vegetation on steep slopes. Hydroseeding is not a solution to this serious problem.

   3. Good quality pre-mining surveys of soils, groundwater and vegetation should be a requirement of any resource development. A record of the pre-disturbance condition is necessary as a guide to the probability of successful reclamation.

   4. Mining companies should be required to accurately and diligently record meteorlogical data for their development area.

The author stressed the importance of trials using shrub cuttings in extreme climatic and soil conditions and the potential development of hybrids incorporating genetic material from indigeneous species.

1. MACYK, T.M.

2. 1974

3. Revegetation of strip mined land at No. 8 Mine, Grand Cache, Alberta.

4. In: D. Hocking and W.R. MacDonald, Editors, Proceedings of a workshop on reclamation of disturbed lands in Alberta, Northern Forest Research Centre, Information Report NOR-X-116, p. 184-188

5. Original

6. a. Alberta; Rocky Mountains

   b. Alpine; Overburden

7. Reclamation at the No. 8 Mine, Grand Cache, located in the Foothills region of Alberta at an elevation of 5,300 feet, began in the spring of 1972.

At this mine, topsoil consisting of the A, B, and C horizons combined together, was saved for replacement. A lack of organic matter resulted in easy compaction and surface crusting of this material. Two sites on backfills and two on southwest-facing slopes were selected for revegetation trials.

Grass species which seemed best in the 1972 and 1973 plantings included Fairway crested wheatgrass, Sawki Russian wildrye, Carlton bromegrass, Boreal creeping red-fescue, intermediate wheatgrass, perennial ryegrass, slender wheatgrass, hard fescue, Nugget bluegrass, and Erica creeping red fescue.

Spring seeding proved to be superior to fall seeding. Mid-summer seeding was poor because of surface soil drying and crust formation. Legume germinants were particularly susceptible to winter kill.

Steep slopes were a problem because of the lack of sites where seeds and fertilizer could lodge on the smooth surface. On steep slopes, grass grew in isolated clumps around stones or in small hollows.

The success of vegetation in micro-depressional sites where better soil moisture conditions prevail, along with wind protection, is evidence of the importance of microtopography for plant establishment. Trees also had increased survival rates where planted in roughened ground which gave some wind protection.

1. MAINS, G.

2. 1977

3. Nutrient cycling: recreating a natural soil and biological system.

4. Paper presented to the Coal Industry Reclamation Symposium, Banff Springs Hotel, February 13-17, 1977, sponsored by The Coal Association of Canada. Unpaged.

5. Original

6. a. Alberta, British Columbia; Rocky Mountains

   b. Alpine; Overburden, Roads

7. The author suggested that in ecosystems where there are adverse or limiting conditions, nutrient cycling mechanisms play a relatively more important role in determining community survival. The adverse conditions for vegetation in alpine and subalpine areas include short growing seasons, heavy sporadic rains, extended winters, and poor nutrient supplies. While many of the relationships between microbes and vascular plants have yet to be worked out for alpine and subalpine areas, the author believes that these relationships are of fundamental importance in designing approaches to reclamation.

The author stressed that non-native species, particularly low elevation grasses, tend to grow well for only a few seasons, outcompeting native varieties, then dying out and giving rise to erosion. Many are not fertile under alpine or subalpine conditions. Native grasses and herbs, if carefully selected, will also contribute to wildlife values. Many native species are only of limited availability at the present time, but with both existing knowledge and with current research underway into means of propagating alpine plants by seeds and cuttings, the time period to commercial availability could be greatly shortened to less than a dozen years. In the choice of plant species, a balance between deep and shallow rooters, nitrogen fixers, and stabilizing varieties is recommended.

Reclamation at high elevations may require several phases of planting to speed the development of "climax-like" communities. Initial seedings with pioneer species, such as alpine timothy, and various needle-grasses could be followed after several years with seeding of intermediate and climax species such as rough fescue and alpine bluegrass. Concurrent with initial seeding, cuttings of native varieties of willow, *Dryas*, huckleberry, heather and alpine sage, could be planted in pockets of organic material, or juniper and kinnikinnick as stabilizing species on slopes.

Continued ...

Mains, G. 1977. Continued

Other researchers have noted that fertilization will often enhance non-native species to the disadvantage of native ones. Although limited fertilization may assist the establishment of pioneer species, continued fertilization will tend to inhibit the development of a new nutrient cycling network.

The author recommended further studies to evaluate those plants most important as mycorrhizal symbionts as well as methods of propagating the mycorrhizal fungi.

1. MARX, D.H.

2. 1975

3. Mycorrhizae and establishment of trees on strip-mined land.

4. The Ohio Journal of Science 75:288-297

5. Original

6. a. World-wide

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. Three classes of mycorrhizae (ectomycorrhizae, endomycorrhizae, and ectoendomycorrhize) are described in terms of their potential value for revegetation of strip-mined land. Ectomycorrhizae occur on many important forest trees. The mycorrhizal association between fungi and the roots of plants is very common in natural soil conditions; in fact, non-mycorrhizal plants are the exception. Ectomycorrhizal infection is initiated from hyphae (propagules) of these fungal symbionts in the rhizosphere of feeder roots where the propagules grow vegetatively over the feeder root surface forming a fungus mantle. By contrast, endomycorrhizal fungi form a loose network of hyphae on feeder root surfaces and most often form large, conspicuous spores on the root surfaces or in the feeder root tissue. Specialized absorbing or nutrient-exchange structures called arbuscules may be formed in the cortex cells and vesicles may also be produced in the cortex by fungi.

Most fungi which form ectomycorrhizae with forest trees are Basidiomycetes; most fungi which form endomycorrhizae with trees are Phytomycetes, primarily belonging to the family *Endogonaceae*. These fungi are dependent on the tree host for essential nutrients to complete their life cycle, especially fruiting. A single tree can have numerous fungi capable of forming mycorrhizae and a single fungus can form such an association with numerous tree species.

Ectoendomycorrhizae are of lesser ecological importance and very little is known of the fungi involved or their significance to tree growth.

Ectomycorrhizae have been found beneficial to tree growth, and for species such as *Pinus* they are indispensible for natural field conditions. Trees with many ectomycorrhizae have a much larger, physiologically active, root-fungus surface area for nutrient and water absorption. Their presence also seems to increase tolerance of trees to drought, high soil temperatures, soil toxins (organic and inorganic), and extremes of soil pH caused by high levels of sulphur or aluminium. The

Continued ...

Marx, D.H. 1975. Continued

fungi of ectomycorrhizae also are active in degradation of organic materials in the soil and certain minerals, make essential nutrients available to the tree and act as a biological deterrent to infection by root pathogens.

Little research has been conducted on the value of endomycorrhizae to trees except to indicate that trees with such an association have more efficient nutrient-absorbing roots, especially for phosphorus. So far it has been determined that only one tree (sweetgum) is dependent on endomycorrhizae in the way *Pinus* is dependent on ectomycorrhizae to become established.

The factors affecting mycorrhizal development are photosynthetic potential and soil fertility. High light intensity and low to moderate soil fertility enhance the degree of mycorrhizal development. Light intensity below 20% of full sunlight and excessively high soil fertility may reduce or eliminate development. In general, the above-ground condition which influences root growth influences in some degree mycorrhizal development. The factors affecting the fungal symbionts directly - extremes of soil temperature, pH, moisture, and the presence of antagonistic soil microorganisms - are those which regulate survival or growth of the infective propagules or vegetative growth on the roots.

Research has shown that certain trees, such as *Pinus*, have an obligate requirement for ectomycorrhizae for normal growth, and introduction of the essential fungi is necessary in afforestation with these trees. Root infection has been ensured by introductions of pure cultures of fungi, soil containing ectomycorrhizal fungi or manipulation of low populations to encourage development.

With regard to strip-mined soils which do not resemble natural soils physically, chemically, or biologically, various researchers have found that early ectomycorrhizal development was essential for seedling establishment of several tree species including two *Betula* species and *Populus tremuloides* on anthracite wastes in Pennsylvania. Seedlings without ectomycorrhizae were chlorotic and died. Four Basidiomycetes were identified from surviving tree seedlings, including *Pisolithus tinctorius*. This last species was in most cases the first symbiont on seedlings and it was suggested that only a few ectomycorrhizae are adaptable to the soil conditions of anthracite waste. Other researchers found formation of some ectomycorrhizae to be temperature controlled and a study of eastern strip-mine waste found *Pisolithus basidiocarps* and its unique gold mycelial strands to be the predominant and, in some instances, the only ectomycorrhizae on roots of *Pinus* and *Betula* species on wastes with pH between 3.5 and 5.5.

Certain ectomycorrhizal fungi are more beneficial to tree growth than others. *Pisolithus* may be more beneficial to the establishment of *Pinus* and *Betula* on strip-mined lands than others. The introduction of

Continued ...

Marx, D.H. 1975. Continued

Pisolithus into seedling nursery soils has improved growth and the practicability of introducing this fungus to containerized seedlings is being examined.

Survival of *Pinus* seedlings with *Pisolithus* ectomycorrhizae at a coal strip-mine site in Kentucky was 45.5% compared to similar seedlings planted with another ectomycorrhizae *Thelephora*, for which survival was only 1.5%. The site had previously been planted five times on a yearly basis with almost complete failure each year. Comparable results were achieved in Ohio for the same two ectomycorrhizae. One problem in research on mycorrhizae is maintenance of the integrity of a specific mycorrhizal association because *Pisolithus* recolonizes roots of test seedlings so rapidly.

Based on a literature search, the author indicates that the geographic distribution of *Pisolithus* is nearly world wide as it has been found in Europe, Asia, Africa, Central and South America and the Middle East. Its host range includes to date 35 species or varieties of pine, two *Eucalyptus*, two *Populus* and possibly six *Quercus*.

The limited research on endomycorrhizae and strip-mined waste has established that endomycorrhizae may be essential for survival and growth of herbaceous plants on coal waste. Abundant endomycorrhizae were found on roots of several herbaceous plants, including grasses, on anthracite and bituminous waste in Scotland and Pennsylvania. On artificially and naturally revegetated coal spoils in Kentucky and Virginia, a variety of wild and cultured grasses were found to be endomycorrhizal to some degree. It is thought the endomycorrhizal infection was present on the planted trees and that they persisted in the coal spoil. Some mycorrhizal infection is evident on wild grasses and on volunteer trees on spoil material; the source is believed to be contamination of the overburden material with the original topsoil. Increase of this source either artificially or naturally could be a way of enhancing revegetation of spoil material. Research is needed on the value of endomycorrhizae to survival and growth of plants on strip-mined lands by testing a variety of fungi which persist on spoil, especially endomycorrhizal fungi with potential such as *Pisolithus tinctorius*. Also, research should determine the value of endomycorrhizae to pioneer plants. Do pioneer plants need them for normal growth, and would succession of herbaceous species be the same if sufficient quantities and quality of endomycorrhizae were present in spoil material?

1. MICHELUTTI, R.
2. 1974
3. How to establish vegetation on high iron-sulphur mine tailings.
4. Canadian Mining Journal 95(10):54-58
5. Original
6. a. Ontario; Canadian Taiga

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. Half of the ore associated with Falconbridge Nickel Mines in the Sudbury Basin consists of waste products. If possible, land-locked basins or lakes are selected as tailings disposal sites but if such natural depressions are unavailable the tailings slimes (generally less than 25 microns in size) are contained behind artificial dams. Such tailings dams represent major problem areas because of acidic seepage (often of pH 3.0 or lower), severe dust storms, and their unsightly appearance.

A vegetative cover offers the best solution to these problems but must overcome a lack of nutrients, the fine particulate nature of tailings, and possible toxic concentrations of heavy metals present, particularly pyrrhotite which produces sulphuric acid to values intolerable to any form of vegetation. Specialized machinery may also be required to revegetate tailings not completely dewatered. The entire tailings must be vegetated at one time to avoid sandblasting of vegetation or burial from unstabilized areas.

Research results since 1970 at the Nickel Rim Mines have indicated the following stages to be necessary in the revegetation of areas with high sulphur content (pyrrhotite): 1) The tailings area should be first covered with a 4 to 6 inch layer of the best locally available soil. If this soil is low in organic content, it should be supplemented with sewage sludge, manure or loam. This should reduce the rate of salt build-up at the surface as well as increase the cation exchange capacity. 2) High grade pulverized agricultural limestone (60%-100 mesh) at 10 tons/acre should then be applied to the soil cover. 3) A 6-9-6 50% urea formaldehyde fertilizer should be applied at a rate of 3/4 tons/acre. The slow release factor of the fertilizer will help sustain the plants for the maximum possible time without maintenance. Instant release fertilizers can dissolve and wash away during periods of heavy rain and be wasted. 4) The seed mixture used at this location consisted of fall rye, bromegrass, red top, colonial bentgrass, creeping red fescue, sheep fescue, sweet clover, purple alfalfa and white clover, with rye applied at 60 lb/acre and the other seeds applied as a combined total at 90 lb/acre. 5) Lastly, a mulch cover of straw is beneficial to protect the young seedlings.

1. MIKHAYLOVSKIY, V.V. and A.A. LOLUA

2. 1976

3. Protection of the environment during the construction of main gaslines in the far north.

4. In: Melnikov, P.I., Editor , Selected abstracts from symposium on environmental protection in relation to economic development of permafrost regions. Corps of Engineers, U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. Draft Translation 518. p. 51-52

5. Original

6. a. U.S.S.R.; East Siberian Taiga

   b. Arctic Islands, Mainland Tundra, Mackenzie Delta Region, Yukon Coast; Roads

7. This translation lists the alternative methods of re-creating an insulating layer once an ice-rich area has been disturbed, including the stripping and replacement of tundra vegetation. The authors point out that, although this method may be relatively inexpensive, there is no assurance that plants with a disturbed root system will create, as before, a uniform insulating cover. This doubt caused the authors to devote research attention to the restoration of plant cover by the seeding of rapidly growing grasses.

In addition to the seeding of grasses and the hydroseeding alternative, the authors discuss the use of woody species. On the Messoyakha-Noril'sk gas pipeline route after filling of the trenches the slopes were strengthened by the planting of alder and willows.

1. MILLBANK, P.

2. 1976

3. Industrial waste heals landscape's toxic scars.

4. Surveyor 147:10-12

5. Original

6. a. Wales; British Forest

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. The Environmental Rehabilitation Unit of the University of Liverpool, established in 1974 under the direction of Professor A. Bradshaw, Department of Botany, is experimenting with non-toxic wastes from the extraction industries as possible ameliorative cover to sustain revegetation on highly toxic spoil heaps. Colliery spoil and wastes from brick, limestone, slate workings and steel slag are such potential cover materials. Planting of metal-tolerant grass is a solution for small inaccessible areas where use of a covering material is not feasible. If such grasses contain up to 1,000 μgm/gm of metal within the plant it is unsuitable for grazing.

Trials were established in Wales using representative plots where the levels were 1.2% lead and 2.5% zinc, both of which are above the threshold at which normal commercial varieties of grass can grow. Treatments consisted of burned colliery spoil, burned colliery spoil plus sewage sludge, steel slag, topsoil, and direct seeding on metal waste, with and without fertilizer. Plots were seeded in May and June. Leguminous plants were not used although interspersing such plants as clover would supply nitrate to the soil but would also require feeding of calcium and phosphorus.

Preliminary results indicate that non-toxic colliery spoil is a useful topping for highly toxic spoil heaps, depending on the ultimate land use. Topsoil is not suitable because it promotes strong and rapid root growth which soon reaches to toxic metal waste below. An extra year of monitoring is planned beyond the initial two years reported here.

1. MILLER, R.M.

2. 1976

3. Some effects on soil microbiota of topsoil storage during surface mining.

4. In: Fourth symposium on surface mining and reclamation, National Coal Association, Washington, D.C., Volume I, p. 131-135

5. Original

6. a. North Dakota; Grasslands

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. Preliminary information gathered from North Dakota suggests that when stockpiled soil is placed over recontoured spoils there is a decrease in the quality of the soil. These disturbed soils characteristically have an increase in bulk density (decrease in porosity), a decrease in water-holding capacity, a reduction in the amount of organic matter, and reduced microbial numbers. The changes are attributed to the method of stockpiling which results in physical mixing of the soil horizons and thus a lowering of organic matter concentration in the soils. The lower layers are compacted by the weight of the upper layers, the magnitude of which is governed by the textural grade of the soil.

Cation exchange capacity and cation concentrations of stored soils tend to be lower than those of undisturbed samples, probably due to the mixing of horizons.

The loss of organic matter from the surface soil is one of the more detrimental aspects. Carbon-nitrogen ratios suggest almost complete immobilization of nitrogen in terms of plant nutrient availability, making nitrogenous fertilizer applications essential to successful revegetation with this soil.

Microbial numbers in stored soils were much lower for all groups of organisms studied. There was also a decrease in the apparent diversity of the algal population. Under storage conditions the dynamic aerobic soil environment becomes essentially anaerobic. The effects of these changes upon the soil microbial community is not precisely known.

A decrease in productivity of disturbed soil is evident. It is caused by several factors, the most prominent one being disruption of physical and biochemical processes. Depth of storage and length of storage also appear to have a substantial impact on soil microbiota.

1. MILLIGAN, A.W. and R.J. BERDUSCO

2. 1977

3. Reclamation problems at high elevations.

4. Paper presented to the Coal Industry Reclamation Symposium, Banff Springs Hotel, February 13-17, 1977, sponsored by The Coal Association of Canada. 13 p

5. Original

6. a. British Columbia; Rocky Mountains

   b. Alpine; Overburden, Roads

7. When Kaiser Resources Ltd. assumed ownership of its present properties in the Crows Nest Coal Field and the Elk River Coal Field it inherited several dormant mine sites that were available for immediate reclamation. These sites have proved more informative over the years than would have been the case with a series of smaller test plots. Species and techniques could be evaluated in relation to slope, aspect and diverse spoil materials on one site. It was also possible to study use of the revegetated areas by wildlife.

Because of the increased pH and lowered organic matter content of spoil material in this area, most native tree species do not fare well, but paper birch and black cottonwood were two exceptions. As far as shrubs are concerned, the authors stressed that there are considerable knowledge gaps about requirements for shrub growth, for seed stratification, and propagation methods.

The authors indicated that although Kaiser Resources Ltd. continues to use agronomic species of grasses and legumes it is recognized that this approach may not be suitable in the long run. They predicted that the use of native species will receive greater emphasis in reclamation work in the years to come, especially at higher elevations. The approach is based on the idea that an initial rapid cover of grasses will not prevent the later planting of shrubs and trees that have been developed in the greenhouse or nursery.

The most important phase of any reclamation program is site preparation. Site preparation has two objectives: re-establishment of watershed values on disturbed sites; and provision of favourable conditions for establishment of vegetation. Experiments indicated that the maximum angle for successful revegetation on fine material is 28°, but 26° was the general objective since it not only resulted in better seedling establishment but also allowed seeding, harrowing and fertilizing. Some recent small scale trials on 30° slopes have resulted in favourable revegetation levels in the Kaiser study area.

Milligan, A.W. and R.J. Berdusco. 1977. Continued

The application of fertilizer to established vegetation has been on an annual basis. No definite time limit has been established as to the number of years this may be necessary until the vegetation becomes self-sustaining. Too little is known about the use of fertilization. A better understanding of the nutrient cycle of these plant communities will allow for a more efficient use of fertilizer.

1. MITCHELL, W.W.

2. 1972

3. Adaptations of species and varieties of grasses for potential use in Alaska.

4. In: B.H. McCown and D.R. Simpson, Co-ordinators, The impact of oil resource development on northern plant communities, 23rd AAAS Alaska Science Conference, University of Alaska, Fairbanks, Alaska, p. 2-6

5. Original

6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra

   b. Northwest Territories, Yukon; Overburden, Roads, Tailings

7. Several cultivars have shown potential for revegetation purposes in boreal Alaska. Of the commercially available plants, grasses have proved to be the best adapted. Bromegrass and timothy are the principal agricultural forage grasses of Alaska with meadow foxtail also used to a lesser degree. For turf, Kentucky bluegrass and red fescue are best. Timothy is preferred in the more coastal regions of the state and bromegrass in the dry interior. However, this information has been gathered from favourable agricultural areas in Alaska and information is both lacking and needed for tundra areas and areas of poor soil unsuited to agriculture.

Revegetation trials involving 13 genera of perennial grasses have been experimentally conducted in a variety of Alaskan climatic regions, including oceanic tundra, cool maritime, insulur coastal, continental interior, alpine, arctic and subarctic. Only boreal and tundra results are discussed in this paper.

In the boreal zone, growing conditions on mesic sites are favourable for several grasses, and some were also successful on drier and wetter sites and in acid conditions of bogs and muskegs. Meadow foxtail, fescues and timothy are best adapted to peaty sites. Bromegrass, fescues, meadow foxtail, certain wheatgrasses and wildrye seem best adapted to boreal dry sites.

Tundra regions are the most limiting because of the cool, short growing season. Alpine tundra areas are more favourable for grasses than arctic tundra areas. Of the commercial grasses, fescues, bluegrasses, meadow foxtail and timothy seem the best adapted to tundra conditions, but varietal differences occur; sometimes one variety will do well in boreal areas and fail in tundra areas. For this reason, discrimination between varieties is very important.

Continued ...

Mitchell, W.W. 1972. Continued

Annual applications of fertilizer are a must in Alaska if grass stands are to maintain high production. Alaskan soils are particularly low in phosphate, and applications of N, P, and K at 500 lb/acre with 80 to 150 lb of phosphate included is advised, with refertilization in the second year as well. Peaty or acid soils give the most problems, especially in terms of nutrient balance and the incidence of disease. Fertilizer rates and ratios can affect disease resistance. Winter survival, which is influenced by disease problems, was poorest in some tests that had higher nitrogen levels. Disease problems tend to occur on sites subject to protracted snowmelt and ponding. Other problems in boreal areas include winterkill from physical stress and snow mould. On the tundra coastal plain most problems are associated with physical stress and few presently commercially available plants can tolerate this stress; disease is less of a problem in this zone despite similar situations such as ponding.

Given sufficient time, native grasses, forbs and woody plants occupy disturbed areas, even making incursions into established grass stands. Continuous management is required to maintain stands of introduced grass if this is the desired goal; if this is not done, native plants invade. The use of introduced plants can improve the site, rendering it more favourable for native plant growth. Many wide ranging native grasses have good potential for disease resistance, such as bluejoint reedgrass (*Calamagrostis canadensis*) and arcticgrass (*Arctagrostis latifolia*). Native plants appear to sacrifice seed production for vegetative growth. Vegetative transplants are used for problem areas but cost factors favour the use of seed. Selection of native plants is therefore based on seed-producing capability and growth characteristics. Once established, native plants adapted to a region and a site grow vigorously and persist without the management necessary for cultivars. Native seed should therefore be included in the mix for an area destined to return to its native condition, but considerable work is required to get appropriate native types in production with sufficient seed available for revegetation purposes.

Aside from the seed production problem with native plants, their seed is often not viable or is difficult to harvest and handle. Also, many native plants perform poorly out of habitat or they winterkill. Their seasonal growth pattern may be upset when moved from their region of adaptation. Large differences exist between biotypes, but this can be a positive factor in selection processes.

The successful introduced grasses in Alaska originated from northern latitudes, mainly Scandinavia and Canada. These commercial varieties have more vigorous seedlings than native plants, the result of selection and breeding.

Testing is required over several years for climatic variation and more information is required on the persistance of stands and management procedures necessary to maintain a good stand of grass.

1. MITCHELL, W.W.
2. 1973
3. Progress with grass variety and fertilization studies in revegetation.
4. In: 23rd Alaska Science Conference, Alaska Division, American Association for the Advancement of Science, College, Alaska, p. 113
5. Author's abstract, with modifications
6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra

   b. Northwest Territories, Yukon; Overburden, Roads, Tailings

7. An overview is presented of revegetation research in diverse areas of Alaska. Many grasses have proved successful in tests on mesic, boreal sites of southern to central interior Alaska. Dry sites are limiting because of moisture conditions but less restrictive than more moist, peaty sites. The latter generally are acidic. Fewer grasses are successful on these sites. Tundra regions with their cooler, shorter growing seasons, are the most limiting. Alpine tundra is more favorable for growth than arctic tundra. Certain fescues, bluegrasses, meadow foxtail, and timothy have demonstrated wide adaptability in Alaska. Alaskan soils require applications of N, P, and K for satisfactory stand establishment. Rates and ratios become more critical on peaty soils where disease problems may also affect winter survival. Native taxa offer good potential for revegetation material that would be more durable and require less maintenance than introduced taxa. Limited material is available now, but work is progressing at the Institute of Agricultural Sciences, University of Alaska, Palmer to provide other, widely adapted materials.

1. MITCHELL, W.W.
2. 1973
3. Using native plant resources for conservation.
4. Agroborealis 5(1):24-25
5. Original
6. a. Alaska; South Coastal

   b. Yukon Coast; Roads

7. Two of the principal colonizers of disturbed sites on Amchitka Island are red fescue (*Festuca rubra*) and Bering hairgrass (*Deschampsia beringensis*). They are being used to revegetate scars incurred by drilling operations, road maintenance and construction activities during a nuclear testing program on that island. The United States Fish and Wildlife Service is reluctant to permit the introduction of exotic species. The Palmer Research Centre is involved in the program because of its comprehensive research on native plant species.

Rehabilitation work began with a survey of the natural revegetation processes and species of the island. Several grasses and some legumes were tested for revegetation purposes. Timothy, some varieties of red fescue, meadow foxtail and experimental Bering hairgrass were found to be superior species.

Native plants on Amchitka Island are poor seed producers. Fortunately, the red fescues found best adapted to Amchitka Island are commercially available, but the Bering hairgrass seed had to be obtained by hand from native stands in late summer. Four hundred pounds were gathered, with about 1.4 million seeds per pound. The hairgrass grows as tall, coarse bunchgrass with long, diffuse inflorescences. It shows particular potential in other regions, both as a conservation grass and a forage grass. Bering hairgrass occurs in natural stands on tideland flats and meadows on Alaska's southern and southwest coasts.

Research is also underway at the Palmer Research Centre to find native species to rehabilitate oil field disturbances. The extreme climate and short growing season of the Alaskan arctic coast are severe limitations on all but native species.

1. MITCHELL, W.W.
2. 1974
3. Native bluejoint: a valuable forage and germplasm resource.
4. Agroborealis 6(1):21-22
5. Original
6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Southern Yukon, Northern Yukon, Yukon Coast; Overburden, Roads

7. Bluejoint reedgrass (*Calamagrostis canadensis*) occurs throughout much of the boreal and north temperate regions, and is particularly luxuriant in Alaska. This grass is an important part of the vegetative economy of southcentral and southwestern Alaska where it invades and stabilizes disturbed areas. It is capable of growth up to 5 ft in 6 weeks when there are 16 to 20 sunlit hours. It can tolerate strongly acidic soils (ranging from 3.5 to 5.5 pH) that remain cool through most of the growing season.

Research at the Institute of Agriculture, University of Alaska, is focussing on management procedures and a better understanding of the several forms of *Calamagrostis* for selection of superior types.

Yields of 1.5 to 2.5 tons/acre (dry matter) have been estimated in native undisturbed stands of bluejoint. Fertilizer applications to bluejoint in the Matanuska Valley of 400 to 700 lb/acre of nitrogen, potassium and phosphorus have produced yields of 1 to 2 tons/acre sustained over several years. The protein content varied between 12 and 20% for forage harvested in July.

In the Kenai Peninsula, fertilizer experiments begun in 1968 have not shown an optimum combination or rate of fertilization. Annual fertilizer applications apparently have an accumulative effect. Applications of 500 lb/acre failed to raise yields appreciably in the initial years but by 1973 500 lb/acre brought bluejoint production to nearly 2 tons/acre. Without fertilization, yields have ranged from 0.50 to 0.75 tons/acre.

The highly variable bluejoint population in Alaska is a genetic resource for selection of superior breeding types. Three chromosomal races occur in Alaska with races of 28, 42 and 56 chromosomes identified. Differences in chromosome number result in trait differences. Plants with 28 chromosomes occur primarily in southwest Alaska with some 56 chromosomal plants at high altitudes. In the interior, plants with 42 chromosomes occur with some of 28 chromosomes.

1. MITCHELL, W.W.
2. 1975
3. Climate reversals and Alaska's grasslands.
4. Agroborealis 7(1):12-15
5. Original
6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Southern Yukon, Northern Yukon, Yukon Coast; Overburden, Roads

7. Possible changes in worldwide climate make Alaska's grasslands all the more valuable for forage and food production. Natural grasslands in Alaska occur above and beyond timberline in the mountain slopes and coastal regions. These grasslands have experienced times of glacial stress and some occupy habitats of almost periglacial nature. They contain genetic types adapted to cooler climates and short growing seasons. Significantly, these native grasslands compare in productivity to rangelands of the midwest tallgrass prairie. Yields of 1.5 to 3.0 tons/acre have been obtained on such undisturbed grasslands.

Smooth bromegrass (*Bromus inermis*) is the most common forage grass in Alaska. Yields of 3 to 5 tons/acre have been achieved with less than 200 lb/acre N applied. Unselected native arcticgrass (*Arctagrostis latifolia*) produced higher yields and greater crude protein content in a comparison with commercial Polar bromegrass and Engmo timothy (Klebesadel 1969). Bering hairgrass (*Deschampsia beringensis*) has produced over 6 tons/acre oven-dry matter with two cuts in one season. Individual types of the latter species are being selected for high yields under harvest pressure. Bluejoint reedgrass (*Calamagrostis canadensis*) is a native grass which grows on strongly acidic soils and gives yields of 1.0 to 2.5 tons/acre when harvested in place but under management and the addition of 150 to 190 lb of N/acre can yield up to 4 tons/acre.

Lands poorly suited for tillage are best left in grass or other vegetative cover which animals can harvest and which then are a potential human food resource. Alaskan grasslands remain green throughout the growing season and do not experience the mid-summer drought of many other grasslands.

1. MITCHELL, W.W.
2. 1976
3. Native grass seed enters commercial production.
4. Agroborealis 8(1):19-21
5. Original
6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Southern Yukon, Northern Yukon, Yukon Coast; Overburden, Roads

7. To hasten re-establishment of vegetation on the 800-mile Alaska oil pipeline, native grass seed will be included in the planting mix as supplies become available. Development of seed supplies is a long process involving: (1) collection of plant material; (2) initial establishment and evaluation of plants in small nursery plots; (3) increase of seed for use in field trials; (4) testing and evaluating; (5) selection of desired types; (6) further seed increase; and (7) release for commercial production.

Two native species will be used by the Alyeska Pipeline Service Company: (1) arcticgrass (*Arctagrostis latifolia*); and (2) bluejoint reedgrass (*Calamagrostis canadensis*), both of which are common throughout Alaska.

Seed was increased by hand-harvesting individual plants at Palmer Research Station. Large plantings can be harvested by small plot machines, but much of the work is hand effort. Threshing and cleaning of seed follows collection, with subsequent marking and storage in a "seed bank". Selection of seed and accurate inventory are important parts of the project.

1. MITCHELL, W.W., J.D. McKENDRICK, F.J. WOODING, and M.A. BARZEE
2. 1974
3. Agronomists on the banks of the Sagavanirktok.
4. Agroborealis 6(1):33-35
5. Original
6. a. Alaska; Alaskan Tundra

   b. Yukon Coast, Mackenzie Delta Region; Roads

7. To meet the challenge of revegetating disturbed sites in the arctic portion of Alaska (north of the Brooks Range), agronomists from the Institute of Agricultural Sciences are involved in various research projects directed to satisfy: 1) immediate needs for stabilizing disturbances, and 2) providing long term solutions that are self-sustaining. Commercial plant varieties which performed well in forested regions failed after their seedling year in arctic Alaska. Commercially available strains of perennial grasses have endured for 3 years, with the most successful being the ones of northern origin. Several annuals have developed good stands in the short-term. A major problem is the lack of commercial seed source of plants used in revegetation trials.

A second problem reported is the attraction that grazing caribou and geese had during late summer and early autumn for revegetation plots, attributed to the earlier senescence of native vegetation than the plot vegetation.

Information was also gathered from a two-year Tundra Biome study in the course of which clones of grasses were transplanted from several locations in Alaska and Colorado to experimental plots for studies on the effect of fertilizers on native grass carbohydrate and nitrogen reserves.

1. MOFFETT, D.
2. 1977
3. Uranium waste researchers consider alternate means of tailing disposal.
4. Canadian Mining Journal 98(1):45-50
5. Original
6. a. Ontario, Mackenzie District, Saskatchewan; Canadian Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Southern Yukon; Tailings

7. Revegetation of inactive uranium mining tailings areas, most of which are at Elliot Lake, Ontario, Beaverlodge, Saskatchewan and Port Radium, Northwest Territories, is a three-stage procedure which results in a self-sustaining grass cover.

The first stage involves removal of surface water and debris to allow the use of agricultural equipment on the fine tailings. The second stage involves application of appropriate amounts of lime and fertilizer, following which the surface is seeded. Treatment normally consists of 10 to 30 tons/acre of limestone and 200 lb/acre of superphosphate fertilizer. The third stage is maintenance of the grass over the next five years, including regular applications of fertilizer.

Alternative methods to surface impoundment of wastes are hydraulic backfill and deep lake disposal, and these are under consideration for the Elliot Lake operations. It is also stated that efforts to revegetate inactive tailings will increase in the future.

1. MOSCHOPEDIS, S.E.

2. 1974

3. Sulfomethylated humic acids as fertilizers and soil conditioners for restoration of sandy soils.

4. In: D. Hocking and W.R. MacDonald, Editors, Proceedings of a Workshop on Reclamation of Disturbed Lands in Alberta, Northern Forest Research Centre, Information Report NOR-X-116, p. 38-54

5. Original

6. a. Alberta; Grasslands

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Tailings

7. Experiments were conducted with coal-derived ammoniated sulfomethylated humates to determine their performance as a fertilizer and conditioner on sandy soils in the Youngstown area, Alberta. Soil humus is an essential part of all fertile soils as a store of plant nutrients and for its binding capability. Humic acids derived from coal resemble those present in soils, a fact which led to this test of coal humus as an aid to increase organic matter and fertility of soils. As a comparison, ammonium nitrate and ammonium sulfate were applied as nitrogen fertilizers.

The sulfomethylated humic acids gave yields that were comparable to those of ammonium sulfate at the same levels of application of nitrogen/ha. The yields of plots fertilized with ammonium nitrate were lower than those of other treatments at the same levels of nitrogen/ha. This is attributed to the extra nutrient (sulfur) supplied by the other treatments.

Yields from sandy soils were poor when compared to yields from the same or other fertilizers in other soils. Nitrogen recovery was low for all treatments. At the same level of nitrogen, the sulfomethylated humates have influences on plant growth comparable to those of other nitrogen-carrying fertilizers. However, the sulfomethylated humic acids significantly increased soil aggregation and moisture-holding capacity.

Sulfomethylated humates of 0.54% and 2.70% by weight improved soil structure by increasing diameters of aggregates from 0.21 mm in the control to 0.57 mm and 1.56 mm in the test plots. In addition, application of the humates reduced hydraulic conductivity, which slows water infiltration. Leaching rates were also reduced through what is believed to be a hydrogen bonding.

1. MOSKALENKO, N.G.

2. 1976

3. Specific features in plant cover recovery along the routes of linear structures in northwestern Siberia.

4. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. Draft Translation 519. 7 p.

5. Original

6. a. U.S.S.R.; East Siberian Taiga

   b. Northern Yukon, Yukon Coast, Central Mackenzie, Mackenzie Delta Region; Roads

7. Observations of plant recovery along routes of unspecified linear structures were made in 1972-73 in the lacustrine-alluvial plain in the Nadym-Kazymskiy interfluve of the Siberian taiga subzone. The plant cover and peaty horizon in certain locations were destroyed in early 1971. Destruction of the plant cover caused changes in soil temperature conditions, intensification or weakening of freezing and thawing processes, and development of cryogenic processes.

Revegetation of the route varied according to the different terrain conditions, moisture and permafrost lithologies (peat, sand or peaty sand). Plant recovery was observed in 11 permanent study areas and contrasted to permanent undisturbed natural conditions.

The areas revegetated least were the crests and upper slopes of hillocks; these are the driest areas and are also subjected to wind erosion and blowing snow. Here isolated *Carex globularis* and occasional red whortleberry with small patches of *Polytrichum* occurred in sand where formerly cedar - marsh rosemary - *Cladonia* thickets existed. In such locations with low peat over sand, marsh rosemary and cloudberry revegetated with the *Carex* and whortleberry to form a total plant cover of only 10 to 15%.

Better conditions for revegetation occurred on central moist slopes, where groups as well as isolated plants grew with plant cover reaching 25%.

Small depressions in sand had a plant cover of 30 to 40% and only in such areas were dwarf birch shoots found. The best recovery occurred in very moist depressions between hillocks where smallreed, smallreed - *Polytrichum*, cloudberry - *Polytrichum*, cottongrass - smallreed,

Continued ...

Moskalenko, N.G. 1976. Continued

sedge - *Polytrichum*, and cloudberry - sedge groupings replaced the former cottongrass - sedge - *Sphagnum* communities.

Small mounds in flat peat bogs were covered by isolated cloudberry plants and single rosemary shoots which developed from surviving dormant buds at the base of cut stems.

It was concluded that plant recovery was unsatisfactory and artificial planting is needed, possibly by planting grass mixtures such as sheep fescue and red fescue with Kentucky bluegrass, species recommended by Filippova for revegetation of light dry soils in the forest-tundra region of western Siberia.

Experimental plantings of Siberian lyme grass began in 1973 and this research will continue over the next several years.

1. MURRAY, D.R.
2. 1971
3. Factors affecting revegetation on uranium mine tailings in the Elliot Lake area. Part I. Physical conditions.
4. Canada Department of Energy Mines and Resources, Mines Branch, Ottawa. Mining Research Centre, Internal Report MR71/104-1D. 12 p
5. Original
6. a. Ontario; Canadian Taiga

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. The physical conditions affecting revegetation of uranium tailings in the Elliot Lake (46 00 N, 83 05 W) area of Ontario are: (1) climate; (2) topography and angle of the sloped tailings; (3) surface conditions of coarse rock and coarse tailings with partly buried dead tree stumps present; (4) areas of shallow ponding with the quality of quicksand, where water and wind erosion are problems; (5) textural segregation of the tailings, with coarse material near the decant tower or near the surface and fine materials further from the decant area and leached down from the surface.

The limiting factors are therefore an excessively high water table, lack of soil structure or cohesion between particles, inability of tailings to support agricultural equipment, water and wind erosion, debris at the perimeters of tailings, and low permeability and slow infiltration of tailings.

To correct these problems, the following measures were recommended: 1) lower the water table and improve drainage of the pond; 2) incorporate large amounts of organic matter in any form (20 to 30 tons/acre) into the tailings; 3) seed selected species in spring at the edges of the tailings; and 4) seed two or three grasses only. Legumes are more difficult to establish and their use is better after another cover is established.

Grass species listed as possible for revegetation of tailings in the Elliot Lake area are:

SCIENTIFIC NAME	COMMON NAME
Phalaris arundinacea	Reed canary grass
Bromus inermis	Bromegrass
Phleum pratense	Timothy

Continued ...

Murray, D.R. 1971. Continued

SCIENTIFIC NAME	COMMON NAME
Poa compressa	Canada bluegrass
Poa pratensis	Kentucky bluegrass
Festuca arundinacea	Tall fescue
Festuca rubra	Creeping red fescue
Agrostis alba	Redtop
Lolium perenne	Perennial ryegrass
Agropyron Spp.	Crested wheatgrass
Agrostis tenuis	Creeping bentgrass
Festuca elatior	Meadow fescue
Dactylis glomerata	Orchardgrass

Species which naturally invaded the tailings, mostly where some organic matter was deposited, included *Equisetum arvense, Amelanchier* sp., *Salix* sp., *Betula* sp., *Polygonum aviculare, Agropyron repens, Agrostis stolonifera, Poa compressa, Poa palustris, Poa pratensis, Carex cephalantha, Glyceria canadensis, Juncus effusus, Typha* sp. and the moss, *Funaria hygrometrica.*

1. MURRAY, D.R.

2. 1973

2. Vegetation of mine waste embankments in Canada.

4. Department of Energy, Mines and Resources, Mines Branch, Ottawa. Information Circular 1C 301. 54 p

5. Original

6. a. Canada

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Tailings

7. In this detailed review, mainly of United States references, some comparisons are made with Canadian overburden and tailings areas in terms of physical properties, chemical properties, climate and vegetation.

The author's review of revegetation attempts in Canada indicated that the following grasses, legumes and trees have been tried:

GRASSES	LEGUMES	TREES
Bromegrass	Alfalfa	Carolina poplar
Canada bluegrass	Sweet clover	Balm of gilead
Timothy	Red clover	Willow
Redtop	Alsike clover	Black alder
Kentucky bluegrass	Birdsfoot trefoil	Paper birch
Crested wheatgrass	Crown vetch	Ash
Creeping red fescue		Black locust
Meadow fescue		Black spruce
Highland bent		Colorado blue spruce
Kentucky No. 31 (New Zealand fescue or Chewing fescue)		Red pine
		Scotch pine
Winter rye		Jack pine
Oats		Douglas fir

Examples of seeding mixtures used for revegetation of spoils in Canada were given as follows:

Mixtures used by INCO

1. 12-1/2 lb Mixed grass seed*
   12-1/2 lb Canada bluegrass
   10 lb Alfalfa or sweet clover
   1-1/2 bu Oats
   8 lb Bromegrass

*Mixed grass seed
1 part Timothy
2 parts Redtop
1 part Kentucky bluegrass
1 part Crested wheatgrass
1 part Creeping red fescue

Continued ...

Murray, D.R. 1973. Continued

2. 12-1/2 lb Mixed grass seed*
   12-1/2 lb Canada bluegrass
   10 lb Bromegrass
   1-1/2 bu Winter rye

Mixtures used by Hollinger

1. 30 lb Timothy
   20 lb Birdsfoot trefoil
   1 lb Crown vetch

2. 20 lb Timothy
   20 lb Birdsfoot trefoil
   20 lb Kentucky No. 31
   1 lb Crown vetch

Miscellaneous Mixtures

1. 20% Meadow fescue
   15% Birdsfoot trefoil
   25% Timothy
   10% Alsike clover
   5% Highland bent
   5% Redtop
   20% Doland red clover

2. Creeping red fescue
   Kentucky bluegrass
   Redtop
   Meadow fescue
   Birdsfoot trefoil
   Timothy
   Alsike clover
   Highland bent
   Red clover
   at 50 lb/acre

3. Kentucky No. 31
   Canada bluegrass
   Crown vetch
   Birdsfoot trefoil
   Timothy

The author discouraged the use of non-vegetative temporary stabilizers because in most cases there will be a demand for vegetative cover on unstable areas. Emulsions are acceptable if they disintegrate and do not hamper plant growth. They are being tried in Canada and should be encouraged because they will be needed in the more difficult areas where slow-growing wild plants are the only possible vegetation.

Although all-purpose fertilizers give good starting results, they should be studied closely. Nitrogen, for example, hinders the proper development of a legume and reduced amounts of it in the fertilizer would benefit both the grass and legume. On spoil, other than that used for agricultural crops, the annual use of fertilizer inhibits the establishment of a natural, self-sustaining vegetation.

In summary, the author concluded that for most spoils in Canada the addition of lime and careful selection of plants will result in satisfactory vegetation. The types of wastes presenting technological problems for revegetation are high-sulphide-content tailings, waste embankments at high elevations, and waste embankments in permafrost regions.

1. MURRAY, D.R.

2. 1977

3. Reclamation by vegetation

4. Paper presented to the Coal Industry Reclamation Symposium, Banff Springs Hotel, February 13-17, 1977, sponsored by The Coal Association of Canada. 3 p

5. Original

6. a. Canada

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Tailings

7. In 1974, CANMET, Department of Energy, Mines and Resources, initiated a three-year study of the potential of vegetation in mine waste reclamation in Canada. Seven hundred mine sites in Canada were evaluated in terms of waste type and extent of vegetation cover using satellite imagery. The results are indicated on maps, at a scale 1:50,000, for waste areas greater than 10 hectares (24.7 acres).

Fifty mine sites were selected as representative of Canadian wastes and these were characterized by 15 physical, chemical and biological properties that were thought to be influential for vegetation establishment.

Three distinct waste types are identified from this analysis: overburden, rock waste and tailings. The distinguishing features of each are described in Supplement 10-1 of the CANMET Pit Slope Manual, available from the Pit Slope Group, Room 235, 555 Booth Street, Ottawa, K1A 0G1.

In addition to waste type identification, Supplement 10-1 identifies four major waste properties which affect plant establishment: climate, particle size distribution, moisture retention and mineralogy. If a problem exists, it will be associated with one of these parameters.

A flow diagram illustrates the steps to determine if vegetation is a practical alternative for reclamation. Four stages are involved:

Stage 1 - Preliminary evaluation - the collection of information which consists of three parts: A - obtaining a mining operation description; B - determining the regional properties of climate and vegetation; and C - determining the waste properties (physical and chemical).

Continued ...

Murray, D.R. 1977. Continued

Stage 2 - Technical evaluation - techniques and alternatives which consists of four parts: D - identify growth limiting factors; E - modify process, change disposal techniques (of most use with new operations where waste properties can be altered without rehandling); F - correct growth limiting factors; and G - growth trials (no proposal should be considered acceptable without demonstrated growth in the field).

Stage 3 - Economic analysis - H - determining vegetation costs and evaluation of cost-benefit.

Stage 4 - Detailed program - I - fullscale vegetation.

The author points out that stages 1 and 3 can be conducted by mine operators; Stages 2 and 4 require specialists in agriculture or reclamation.

Evaluation of the necessity for an alternative to revegetation in reclamation is step J. This would be the case if the problems with correcting growth-limiting factors were insurmountable, if the vegetation costs and cost-benefit analysis were unfavourable, or if growth trials failed.

The Pit Slope Manual that will be published as a result of the CANMET study is designed to give operators adequate information to realize the capabilities and limitations of revegetation as a method of reclamation. It is not intended as a field recipe for methods of revegetation.

1. O'TOOLE, K.
2. 1974
3. Nuera - reclamation to preserve Alaska.
4. Alaska Construction and Oil 15(6):32, 34
5. Original
6. a. Alaska; Central Alaska Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. Nuera Reclamation Incorporated, a subsidiary of Usibelli Corporation, has been involved for the past several years in reseeding and reclamation projects in Alaska and, in particular, reclamation for the Usibelli Coal Mine at Healy. The president of Nuera, D. Moncrieff, reports that erosion control is the prime concern with aesthetics of secondary importance.

Nuera uses aerial application with a Cessna Agwagon for seed and fertilizer distribution. Fixed-wing aircraft are preferred over helicopters for more consistent seed distribution. Hand operated seeders are used for small areas or in some cases hydroseeders where these are useable. With aircraft, the time of seeding can be more precise and can be accomplished in a short time that coincides with the optimal seeding time.

Nuera participated in the reclamation of the Usibelli Coal Mine over the past three years, involving revegetation of nearly 17,000 acres. Here the perennially frozen soil was removed in the initial mining operation before coal was mined. After mining, Nuera fertilized and seeded the area with good results. Dall sheep in the area have been attracted by the new lush vegetation and also have borne young close to the mining operation, the noise of which had deterred predatory wolves.

This is the largest reclamation project in northern latitudes and has involved 400 tons of high concentration fertilizer and 60 lb of special seed mixture. Increasingly, problems of supply and rising prices of fertilizer and seed are a challenge to such operations.

1. PACKER, P.E.
2. 1974
3. Rehabilitation potentials and limitations of surface-mined land in the northern Great Plains.
4. U.S. Department of Agriculture, Forest Service, Intermountain Forest Range Experiment Station, Ogden, Utah. General Technical Report INT - 14. 44 p
5. Original
6. a. United States; Grasslands

   b. Yukon and Northwest Territories; Overburden, Tailings

7. This report on the rehabilitation potential of surface-mined land in the northern Great Plains of the United States, contains a list of information and research needs. Most surface mining activity at this temperate location coal province has developed within the past seven or eight years and nearly all rehabilitation efforts have occurred within the last five years.

The list of information and research needs, reproduced below, contains general principles that would be applicable to reclamation research programs in other regions:

1. Analyze and evaluate chemical and physical characteristics of surface-mine overburden materials before mining in relation to their suitability for revegetation purposes;
2. Test and evaluate various spoil segregations and configurations for enhancement of rehabilitation success;
3. Develop methods and techniques for creating favorable microbiological activity in previously sterile surface-mine spoils;
4. Test and evaluate the comparative effects of different organic soil amendments in the revegetation of surface-mine spoils;
5. Test and evaluate comparative effects of selected inorganic fertilizers in the revegetation of surface-mine spoils;
6. Evaluate the physical and chemical quality of surface and subsurface runoff water from mine spoils under different rehabilitation treatments;
7. Develop mechanical-chemical-vegetative techniques for rehabilitating steep, abandoned surface-mine spoils;

Continued ...

Packer, P.E. 1974. Continued.

8. Evaluate the effectiveness of semiarid farming techniques known to be effective on various kinds of mine spoils;
9. Determine limits of establishment techniques identified in 8 (above);
10. Develop mechanical criteria for construction of mine dumps or massive spoils to prevent mass slumping and to reduce surface erosion;
11. Determine the physiological tolerances of selected plant ecotypes to various soil-water potential stresses and atmospheric evaporative-demand stresses on surface-mine spoil sites;
12. Determine physiological tolerances of selected plant ecotypes to saline-alkaline stresses on various kinds of surface-mine spoils;
13. Test and evaluate hormone-stimulated rooting characteristics of native shrubs on abandoned, oversteep mine spoils;
14. Apply tissue-culturing techniques to develop increased tolerances of selected plant ecotypes to saline-alkaline stresses on surface-mine spoils;
15. Determine post-treatment management practices requisite to successful permanent revegetation.

1. PETERS, T.H.
2. 1970
3. Using vegetation to stabilize mine tailings.
4. Journal of Soil and Water Conservation 25:65-66
5. Original
6. a. Ontario; Canadian Taiga

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. Experiments conducted by International Nickel in southern Ontario to stabilize tailings from concentrators are described. Based on previous research the revegetation program was designed to include the following steps: (1) seedings made as close as possible to the windward edge of the tailings area; (2) a companion or nurse crop should be planted to provide shade and shelter; (3) plant nutrients should be added, with limestone additions to permit tailings pH to approach neutral.

Seedings in August were generally more successful when temperatures were cooler and moisture more available. Feed grade limestone, as opposed to agricultural limestone, is coarser and breaks down more slowly providing a longer buffering period. This was applied at rates of 3 tons/acre and disced into the soil. Application of limestone was repeated in mid-July. Fertilizer of 5-20-20 was applied at rates of 400 lb/acre with annual maintenance applications subsequently. A seed mix of equal parts of Canada bluegrass and a seed mix (timothy, redtop, Kentucky bluegrass, crested wheatgrass and creeping red fescue) was made with fall rye as a companion crop. Bromegrass was seeded after this initial seeding and the seedbed was then firmed with a cultipacker.

Over 600 acres have been established to grass, some of which has been harvested for hay. Trees, principally birch, are voluntarily growing from seed throughout the area.

1. PETERSON, E.B. and H.M. ETTER

2. 1970

3. A background for disturbed land reclamation and research in the Rocky Mountain region of Alberta.

4. Canadian Forestry Service, Forest Research Laboratory, Edmonton, Alberta, Information Report A-X-34. 45 p

5. Original

6. a. Alberta; Rocky Mountains

   b. Alpine, Southwestern Mackenzie, Southern Yukon; Overburden

7. For this review article, the word 'reclamation' was interpreted broadly to include any process that promotes soil conservation and productive land use of disturbed land. Reclamation involves three distinct phases: (1) prior land-use planning, (2) physical operations to achieve a suitable topography and (3) natural or assisted revegetation and subsequent management of reclaimed land.

The authors stressed that reclamation according to an advance land-use plan provides a basis for evaluating many of the individual steps in the reclamation operation. It eliminates as a sole objective the rapid establishment of a green cover; instead, initial plantings are considered only as a first step in soil conservation. Subsequent vegetation management is usually necessary to achieve the projected land-use.

The major physical steps in reclamation are placement of spoil at desired slopes, backfilling the highwall, contouring or terracing, and setting drainage patterns. Where assisted revegetation is to follow, it may also be necessary to break up compacted surfaces, adjust the micro-topography, or cover with suitable strata to ensure the growth of desired species.

The authors indicated that it is difficult to justify any delay in revegetation in the Rocky Mountain region since there appear to be no major acidity or toxicity conditions which could be moderated by weathering. It follows that revegetation in mountainous regions should be undertaken as soon as possible after a disturbance and before the finer soil particles are washed downhill or into the profile.

Ecotypes which have evolved on disturbed lands frequently possess high tolerances to conditions on those particular sites, and in mountainous terrain it is often cheaper to utilize these tolerant ecotypes than it is to apply corrective surface treatments. Hence, one begins species selection by collecting reproductive material from ecotypes or clones that are established on the oldest disturbed sites in a particular ecological or altitudinal zone. In Britain, this concept has developed to the

Continued ...

Peterson, E.B. and H.M. Etter. 1970. Continued

point that ecotype selection and seed production on the reclamation site are now considered to be as important as surface treatments.

It is extremely important to carry out thorough screening before a species is used in a large-scale reclamation program. When a stringent evaluation technique is used, very few species pass the test. For example, in the 10 years preceding 1970, only 15 species and varieties were approved by the Soil Conservation Service for revegetation use on specific sites in the northeastern United States. Until the results of screening tests are available for any given region in which revegetation is to be attempted, the best approach is to use candidate species which possess as many as possible of the following characteristics:

(1) native or naturalized species;

(2) ability to regenerate naturally on industrially disturbed land, or in severe natural habitats such as avalanche slopes, eroding river banks, recent glacial moraines or wind-blown ridges;

(3) proven effective in reclamation work elsewhere;

(4) high value for specific land-use objectives;

(5) readily reproducible in large quantities by natural or artificial means;

(6) low water and nutrient requirements;

(7) high rate of root dry-matter production; and

(8) nitrogen-fixing ability.

1. PIPELINE APPLICATION ASSESSMENT GROUP

2. 1974

3. Revegetation

4. In: Mackenzie Valley Pipeline Assessment, Environmental and Socio-economic Effects of the Proposed Canadian Arctic Gas Pipeline on the Northwest Territories and Yukon, Department of Indian Affairs and Northern Development, Ottawa, Chapter 8, Section 8.14, p. 256-268

5. Original

6. a. Mackenzie District, Yukon; Canadian Taiga, Canadian Tundra

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Northern Yukon, Yukon Coast; Roads

7. The general conclusion advanced by the Pipeline Application Assessment Group was that the Canadian Arctic Gas Pipeline Ltd. proposal relied too much on seeded grasses to re-establish a sufficiently protective and insulative vegetative cover. The Assessment Group considered that more varied and elaborate revegetation measures would be needed.

The stated objectives of the revegetation program were to restore a favourable soil heat-balance by providing an insulating cover, to provide - along with mechanical means - drainage and erosion control, to promote slope stability, to restore lost habitat, and to improve the aesthetics of the facility. Many of the concerns recorded in this report centre on questions of whether or not revegetation can achieve these stated objectives.

There is a general lack of information on the rate of accumulation of organic matter beneath natural or assisted revegetation on disturbed areas. The Assessment Group suggested that at this time conclusions about litter accumulation under seeded agronomic grasses and its effect on permafrost would be premature, and also suggested that there was considerable doubt that seeded grasses can quickly restore permafrost levels to their pre-disturbance state. Other researchers have found that, following fire, the permafrost table in hummocky terrain began to rise 60 to 80 years after the establishment of trees, attaining its pre-disturbance level by 100 years, but that the organic layer did not develop its pre-disturbance thickness for at least 150 years.

The Assessment Group suggested that rooting characteristics, particularly in relation to erosion control, were given inadequate attention during the selection of grass species for revegetation in the Mackenzie River valley. The selection of species and procedures focussed on whether

Continued ...

Pipeline Application Assessment Group. 1974. Continued

the species would provide insulation and promote a rapid return to pre-disturbance soil thermal conditions. The vegetative characteristics, beyond survival, that are important in the control of erosion, such as rooting characteristics and growth habit, have received little attention. While the species chosen may, in fact, be the best for the control of erosion, this is not certain from the documentation supplied with the application.

The use of fixed-wing aircraft and helicopters in the aerial application of grass seed and fertilizer is also a concern. Differences among grass species in seed size and weight, direction and speed of wind, and aircraft altitude can cause a highly variable distribution of the seed mix along the right-of-way. Although such variability may not be important along those pipeline sections where the effects of revegetation are largely cosmetic, it is important where erosion is a problem and the establishment of a vigorous grass stand is required. Here, seeding by ground crews should be considered as the preferred alternative.

The Assessment Group stressed that in selecting grass species it will be important to test seed mixtures rather than single species, to measure soil-binding capability rather than top growth, and to evaluate performance over the range of soil and climate that will be encountered.

1. PLASS, W.P.
2. 1975
3. Reclamation of surface-mined land.
4. The Ohio Journal of Science 75:298-304
5. Original with author's table.
6. a. United States; Eastern Forest

   b. Yukon and Northwest Territories; Overburden, Tailings

7. The technology to revegetate lands disturbed by surface mining in the midwestern and Appalachian coal fields of the United States is well advanced. Basic to the future success of maximizing the productivity of mined land is a scheme for pre-mining and post-mining evaluation. The components of a coordinated mining and reclamation program as tabulated in this article, are:

I PREMINING EVALUATION TO IDENTIFY LAND-USE OPTIONS

Mining:

Quality of coal
Quantity of coal
Overburden characteristics

Reclamation:

Overburden characteristics
Geographic location
Topographic features
Local land-use patterns
Legal limitations
Political factors
Social factors

II POST-MINING EVALUATION TO SELECT THE MOST ATTRACTIVE LAND USE

Chemical characteristics of the spoil
Physical characteristics of the spoil
Climatic variables
Topographic variables
Economic variables

Continued ...

Plass, W.P. 1975. Continued

III REVEGETATION TREATMENTS TO ACHIEVE LAND-USE OBJECTIVE

Site Preparation

- Amendments:
  - Fertilizers (nutrient supplements)
  - Neutralizing material (chemical and physical soil modifier)
  - Top soiling
- Surface modification:
  - Seedbed preparation
  - Moisture retention
  - Modify surface temperatures
  - Reduce wind volocities
- Species selection:
  - Compatability with spoil characteristics
  - Season of seeding
  - Species compatability
  - Climatic and topographic factors
  - Land-use objective
- Seeding and planting systems:
  - Acreage to be treated
  - Physical characteristics of the spoil
  - Configuration of the surface

IV MAINTENANCE SYSTEMS

- Vegetation characteristics
- Chemical and physical characteristics of the spoil
- Climatic variables
- Topographic variables
- Economic variables

In the pre-mining evaluation, overburden materials should be viewed as a resource to be systematically placed to reduce pollution hazard and create a desirable plant medium. The post-mining evaluation documents the actual condition and characteristics of the re-shaped spoil so that the revegetation plan can be developed. Spoil pH is regarded as an indicator of soil quality which determines the availability of nutrients and toxic ions to plants. Revegetation guides based on pH and texture have been developed for acidic spoils of the eastern United States and similar guides may be developed for the alkaline spoils characteristic of the western United States.

Most spoils are deficient in nitrogen and phosphorus with potassium usually adequate to maintain a vegetative cover; supplements of potassium may be needed for forage or row crops. Agricultural limestone or industrial wastes such as power-plant fly ash, bottom ash and alkaline industrial slag are most frequently used to neutralize acid spoils. Where possible, this neutralizing material should be incorporated to depths of 6 to 8 inches in the spoil by mechanical means. Where mechanical treatments are not possible, then neutralizing material can be left to mix by frost action or infiltrating waters.

Continued ...

Plass, W.P. 1975. Continued

Topsoil is used where surface spoil is difficult to revegetate. The topsoil is spread with a mixture of all natural horizons because seldom is it possible to segregate the most productive horizon. The depth of topsoil is determined by the problem to be corrected; low pH areas require 12 inches or more of topsoil. The expense of topsoiling has to be weighed against selective placing of overburden.

Many spoils develop a hard surface crust as they dry which can be detrimental to germination and seeding density. This could be overcome by scarification before seeding, or seeding as soon as the slope is formed or freshly graded.

Depressions, furrows and artificial barriers such as snow fences help to trap precipitation, modify the surface temperatures, and reduce the effect of wind on spoil surfaces. The orientation of these features to sun exposure and prevailing winds determines their effectiveness.

Quick vegetation covers established for erosion control utilize annual grasses which develop fibrous root systems and much foliage. As perennials seeded with annuals often fail from competition, the revegetation plan should include provision to establish a perennial ground cover later. Native grasses develop slowly and require two or three growing seasons to establish as an erosion control cover, and there are problems of seed supply. However, native grasses, forbs and leguminous species are considered for extremely harsh environments in the western United States. Woody species are selected for permanent site protection, forest crops and wildlife food and cover. A major requirement of revegetation is production of a quick surface cover, often using mixes which ignore species compatibility which can result in increased maintenance to retain the desired density of cover. Some grasses and legumes are more compatible than others and the influence of various mixtures on tree growth is being studied.

1. PRICE, L.W.

2. 1969

3. The collapse of solifluction lobes as a factor in vegetating blockfields.

4. Arctic 22:395-402

5. Original

6. a. Yukon; Southern Yukon

   b. Alpine; Overburden, Roads

7. Blockfields (felsenmeer) are slopes or level areas consisting of large and small angular blocks believed to be the result of rapid mechanical weathering of bedrock in place. Such areas exhibit a lack of fines which means an almost complete absence of soil. There is also a lack of water near the surface and great diurnal extremes of temperature.

Scattered strips of soil and vegetation in a blockfield observed in the Ruby Mountains of southwest Yukon Territory are believed derived from collapsed upslope solifluction lobes which gave way to mud-flows. These mud-flows transported into the blockfield clumps of vegetation which became established along the mud-channel margin or levee. The lobes collapse when they pass over the abrupt break in slope between the alb and lower valley slope where in this instance the slope increased by 10° to 12°. Plant species composition also changes with changed angle to the sun reflecting species capable of growth in drier conditions: *Dryas octopetala, Festuca altaica, Polygonum viviparum* and *Cassiope tetragona* which replace the tussock species, principally *Salix pseudopolaris, Carex microchaeta, Salix reticulata* and *Eriophorum angustifolium.*

Many tundra plants reproduce vegetatively. If a transported clump and associated plants can become established before being carried away by erosion, a small island of vegetation is established and some semblance of stability is maintained until the process repeats. The process is very slow and evidence points to the fact that the collapse of solifluction lobes is one way certain arctic and alpine slopes are vegetated more quickly than otherwise.

1. PROVINCE OF BRITISH COLUMBIA

2. 1977

3. Guidelines for coal and mineral exploration.

4. Ministry of Mines and Petroleum Resources, Inspection and Engineering Division, Victoria. 63 p

5. Original

6. a. British Columbia; Coastal, Interior, Rocky Mountains

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads, Tailings

7. These guidelines were written with the object of assisting individuals and companies who are engaged in coal and mineral exploration in British Columbia to carry out their work with due regard for the Province's other resources. Emphasis is placed on the need to provide planning time and a budget sufficient to safeguard the landscape, biological resources, and other uses in project development.

It is not possible or desirable to write detailed regulations within which industry must totally work considering the complexities of the exploration field and the many natural resources of British Columbia. It is essential however to the minimizing of disturbance that industry maintain a significant level of effort to achieve environmental control, and the most important aspect here is the assignment of reclamation management to capable staff. On larger projects this of course is a full-time job.

These guidelines are intended to convey concepts of good practice, including general guidelines for revegetation which suggest that:

1. Topsoils shall be salvaged to the maximum depth of vegetative rooting, and disturbed areas shall be surface dressed with this soil on completion of operations.

2. Revegetation shall be either seeding to appropriate mixtures of grass and legumes species or reforestation. Mines ecological personnel will advise as to the preferred method and will advise on the proper grass/legume seed mixtures. Seed and equipment should be on hand at the start of exploration.

3. Additional information on fertilizer requirements may be obtained by sending soil samples to the Ministry of Agriculture, Soils Testing Laboratory, Kelowna. Soil sampling instructions and sample containers are available from them on request. Cost of each sample tested is approximately $3.00 (1976).

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Province of British Columbia. 1977. Continued

4. In the event that the operator is unable to obtain specific advice for his operating site, the following rough guide may be used:

(a) Seeding shall be done at a rate of approximately 25 pounds per acre. This should be doubled for alpine areas.

(b) All legumes should be double inoculated.

(c) Rhizomatous or creeping varieties of alfalfa should be used in the Interior.

(d) Birdsfoot Trefoil may be substituted for alfalfa in the wetter areas.

(e) Slow release type fertilizers should be applied at a rate of 200 pounds per acre. A 20-24-15 fertilizer blend is recommended.

(f) Seeding and fertilizing should be done as early as possible (before hard frosts), preferably early spring. This entails return to the site the following year for reclamation. Fall seeding may be approved in certain cases. Small or inaccessible sites are best seeded with hand-operated 'Cyclone' seeders. Road systems may be treated with either hand seeders or power take-off 'Cyclone' seeders mounted on a four-wheel-drive vehicle.

A separate guideline is provided for seed mixtures intended for use on adit, trench, and test pit waste materials where a surface dressing of salvaged topsoil exists. These suggested seed mixtures for reclamation of exploration operations are as follows for the north-central, alpine and subalpine parts of British Columbia (the portions of the province most resembling areas north of 60°):

Area	Altitude (feet)	Vegetation type	Seed mixture
North-central	1,700 - 3,000	Douglas fir and aspen parklands/ white spruce/black spruce/birch	Timothy, 30%; smooth brome, 20%; boreal creeping red fescue, 20%; intermediate wheatgrass, 15%; alsike, 5%, alfalfa, 10%
Alpine and subalpine areas throughout province, and far north part of province	3,000 - 7,000	Engelmann spruce/ subalpine fir, alpine meadows, tundra	Pubescent wheatgrass, 20%; meadow foxtail, 20%; crested wheatgrass, 15%; smooth brome, 15%; hard fescue, 10%; tall wheatgrass, 10%; boreal creeping red fescue, 10%

1. ROOT, J.D.

2. 1973

3. The physical environment of an abandoned strip-mine near Cadomin, Alberta.

4. University of Alberta, Edmonton, Alberta. M.Sc. Thesis. 100 p.

5. Original

6. a. Alberta; Rocky Mountains

   b. Alpine; Overburden

7. The abandoned coal mine site at Cadomin, Alberta, in the Alberta Foothills was studied in 1971, after mining operations ceased in 1952. Approximately 350 acres were disturbed by surface mining and no effort was made to reclaim the areas. The site therefore provided an opportunity to examine the effects of long-term natural revegetation, potential slope stability and erosion problems.

The natural topography is rugged with a combination of steep slopes and flat surfaces. Vegetation surrounding the mine is primarily lodgepole pine - white spruce - Engelmann spruce with some balsam poplar and alder. The area is at an altitude of 1,675 m.a.s.l., which is just below the tree line on the flank of the Nikanassin Range. This range acts as a barrier to the easterly flow of Pacific air, except for wind that funnels through a gap by the McLeod River; high winds are a characteristic feature of the area.

The basic conclusion of this thesis is that microclimate, and not geologic conditions, is the principle limiting factor for natural revegetation at the mine site.

The spoils left by mining consist of fractured sandstone, shale, coal and minor conglomerate and ironstone of the Luscar Formation. These materials weather rapidly, particularly the shale and softer sandstone, through frost-wedging. The spoil is in steep-sloped piles but little mass wasting occurs and the spoils are relatively stable. Talus creep and rock creep are the dominant mass-wasting processes. Some erosion by running water has created gullies but this is relatively minor because the strong winds remove snow cover and the spoils are highly permeable.

Seed supply, soil moisture and high winter winds are the three dominant factors controlling natural revegetation. Vegetation occurs in areas that are protected from the wind, which have adequate soil moisture or

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Root, J.D. 1973. Continued

spring discharge and which have a snow cover during winter. Generally vegetation is more abundant at the west end of the mine site and decreases eastward. This is attributed to greater wind fetch at the eastern end of the site, leading to higher evapotranspiration, greater snow removal, abrasion of plants by particles and plant injury.

The spoil materials are fertile, with the exception of coal, but the steep slopes limit vegetation by the rapid downslope movement of frost-shattered, fine-grained material and wind transported fine rock debris. Slopes are therefore almost devoid of vegetation. Vegetation on the flat surfaces of spoil is limited by abrasion, by wind-borne rock particles, and by a deflation pavement from which all fines have been removed. Accumulation of wind borne rock particles below the mine site have had the effect of burying understory vegetation there and retarding growth.

Plants within the mine site are largely prostrate, decumbent, or creeping and frequently exhibit a dense growth of overlapping leaves. Spreading or deep penetrating root systems and rhizomes are important for survival and vegetative reproduction. Plants grow in wind protected places such as the lee sides of boulders and logs and in depressions and hollows. Seeds are also wind borne and settle in such wind protected locations. However, high winds tend to remove from the mine site any seeds that are produced there. Plants are frequently located at the break in slope at the spoil base. Most plants that grow on this mine site are adapted to rocky, gravelly, sandy, moisture deficient, wind-swept habitats that are typical of high alpine regions.

For assisted revegetation to be successful in the Alberta foothills, measures must be found to reduce moisture deficiency and wind velocity. Compaction of soil, accumulation by the use of snow fences, mixing organic material with surface spoil, and the creation of a rough micro-topography are all potential methods for control of wind and moisture deficiency.

Ten different plant communities were identified according to relative dominance of various combinations of the following species or plant groups: *Crepis nana*; grasses; *Achillea millefolium*; sedges; *Trifolium* spp; *Taraxacum officinale; Equisetum* spp; *Alnus crispa; Picea engelmanii;* and *Pinus contorta.*

1. SCARBOROUGH, A.M. and P.W. FLANAGAN

2. 1972

3. Observations on the effects of mechanical disturbance and oil on soil microbial populations.

4. In: B.H. McCown and B.R. Simpson, Co-ordinators, The impact of oil resource development on northern plant communities, 23rd AAAS Alaskan Science Conference, University of Alaska, Fairbanks, Alaska, p 63-71

5. Original

6. a. Alaska; Central Alaska Taiga, Alaskan Tundra

   b. Yukon Coast, Mackenzie Delta Region; Roads

7. It is increasingly apparent that fungi in tundra and taiga areas play a major role in deterioration of organic remains and the recycling of bound nutrients for uptake by higher plants. In this study, microfungal decomposers isolated from natural, disturbed and oiled soils were analyzed from sample sites at Barrow, Prudhoe Bay, Sagwon, Hess Creek and College, all in Alaska. Results from the several sites show a common pattern. The effects of mechanical disturbance compared to undisturbed sites were a decrease in soil acidity, an increase in bacterial and yeast biomass, and a decrease in fungal species, density, biomass and activity. The observations from all sites indicate that a major upheaval occurred in nutrient release and recycling, and it is not known if this is a temporary or permanent change. The results of the changes will be reflected in the primary productivity of the amended areas. Only study over time can determine whether the system returns to its former state or whether a new climax of vegetation and microbial populations occurs. Preliminary results two years after disturbance from disturbed and oiled sites indicate that the original microflora had not returned.

At one site at College, 122 species of microfungi were identified from soils of the undisturbed study area, and 83 were identified from the disturbed area. In the disturbed area, all trees and underbrush were removed by bulldozer, and the litter turned into the mineral soil over the experimental heated pipe. The disturbed area was changed drastically abiotically and microbiologically, and pH changed from acid to alkaline. The changes in pH select for entirely different plant and microbial communities, and removal of litter and the organic acids contained in litter results in a loss of acidifying agents which could account for the increased pH and greater bacterial biomass. Some species

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Scarborough, A.M. and P.W. Flanagan. 1972. Continued

occurring in high numbers in the undisturbed area were reduced in number or were absent from the disturbed area. The changes in species components is explained by the absence of the litter layer and an influx of fungi on non-sterilized seeds used for revegetation.

Microbiological differences were noted in comparisons of various tundra areas. In Barrow soils, yeasts are predominant and their variety and numbers indicate that they are most active in decomposition, with some indication of increase in numbers with depth. The Prudhoe Bay area is quite different and shares only 15 microbial species with Barrow of their combined total of 94 species. Yeast biomass was 15 times greater at Barrow than at Prudhoe Bay, with the exception of the oiled revegetation sites which had the highest biomass.

1. SCHOENIKE, R.E.
2. 1958
3. Influence of mountain avens (*Dryas drummondii*) on growth of young cottonwoods (*Populus trichocarpa*) at Glacier Bay, Alaska.
4. Proceedings Minnesota Academy of Science 25-26:55-58
5. Original
6. a. Alaska; South Coastal

   b. Alpine, Southern Yukon, Northern Yukon; Overburden, Roads

7. In this study, cottonwood saplings located in areas dominated by *Dryas* were compared to cottonwood saplings growing in areas free of *Dryas* in Muir Inlet of Glacier Bay, Alaska. Comparative height measurements showed that *Dryas*-associated cottonwoods grew faster, averaging 2.43 inches/year compared to 2.02 inches/year for cottonwoods in areas away from *Dryas*. No consistent differences were evident in basal diameter growth, number of live branches or size of leaves of the two groups.

Analysis of leaves of *Dryas* indicated 1.84% nitrogen (oven dry weight) compared to 2.56 to 3.65% for alder. Leaves of *Dryas*-associated and *Dryas*-free cottonwoods showed little difference in their nitrogen content. The author concluded that *Dryas* colonies stimulate height growth in cottonwood saplings but to a lesser degree than that produced by alder. *Dryas drummondii* has an affinity for recently glaciated areas. Its present range is primarily in western North America from Central Alaska south to Oregon and east to Great Slave Lake.

1. SCHOPMEYER, C.S.

2. 1974

3. Seeds of woody plants in the United States.

4. U.S. Department of Agriculture, Forest Service, Washington, D.C.
Agriculture Handbook No. 450. 883 p

5. Original

6. a. United States

b. Yukon and Northwest Territories; Overburden, Roads

7. This handbook, which supersedes the *Woody Plant Seed Manual*, Miscellaneous Publication No. 654 (1948), is written for everyone who works with tree and shrub seeds. The text is divided into two major parts. Part 1 describes the principles and general methods of producing and handling seeds. Eight chapters outline seed biology, the principles of genetic improvement of seed, production of genetically improved seed, pollen handling, harvesting, processing and storage of fruits and seeds, presowing treatment of seed to speed germination, seed testing and tree-seed marketing controls.

Part 2, which constitutes the major portion of the text, provides specific handling methods and data for seeds of 188 genera which include most of the tree and shrub genera that occur in the North. As an example of the kind of information provided for each genus, the description of *Salix* includes growth habit, occurrence and use, flowering and fruiting, collection of fruits, extraction and storage of seeds, germination tests and nursery practice. Where appropriate within a genus, separate tables indicate for each species the nomenclature, occurrence, phenology of flowing and fruiting, seed-bearing and fruit ripeness criteria, the number of cleaned seeds per pound, germination test conditions, and germination results. A separate reference list also accompanies each genus description plus photographs of seed shape and structure.

1. SCHWENDIMAN, J.L.

2. 1973

3. Site preparation and seeding methods for critical areas.

4. In: 1973 Alaska Revegetation Workshop Notes, Co-operative Extension Services, University of Alaska, Fairbanks, RP-239, p 38-40

5. Original

6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra

   b. Yukon and Northwest Territories; Overburden, Roads, Tailings

7. Successful revegetation requires adequate site preparation. The necessary principles and practices for revegetation are: good water disposal measures; elimination of competition; preparation of a good seedbed for correct seeding depth; good seed of adapted species; seeding at the proper season, rate, time and depth; and use of fertilizer, mulch and protective cover until vegetation is established.

Thorough on-site inspection to determine the extent of site preparation required involves information on soil texture, soil depth, organic matter, fertility, water-holding capacity, infiltration rate, slope, erodibility and soil pH. In addition, assessment is needed of the following climatic factors: annual rainfall and seasonal distribution of rainfall; intensity of storms and variation over several years; depth and duration of snowcover; length of growing season; duration of maximum and minimum temperatures; presence of permafrost and depth and duration of frozen soil.

Seeding methods should be suited to the environment. Drill plantings are limited to gentle slopes of less than 3:1. Increased seeding rates are not a substitute for good site preparation. Diluting material, such as rice hulls, can improve seed distribution.

Broadcasting of seed is most successful on rough, bare, fertile sites that are protected from wind and water erosion. Seed coverage by soil or mulch is a necessary part of broadcast seeding. Broadcasting is faster and cheaper than drill seeding but even distribution may be difficult to achieve because of wind. Broadcast seeding is best for rough country but involves almost double seeding rates.

Drill seeding is the most successful but is limited to situations and seasons where machinery can be used. One particular drill, the Rangeland drill, is designed for rough country. Less seed is required with a good drill which distributes seed, places it at proper depth and covers it lightly. One disadvantage is that it is a slower process than either

Continued ...

Schwendiman, J.L. 1973. Continued

aerial or broadcast seeding.

Aerial seeding is best suited for large sloping areas or elongated areas such as roadsides. Helicopters offer more versatility, more uniform seed distribution and a quick method of seeding a large rough area.

Hydroseeding is preferred for slopes where drilling is not feasible but where there is access to the area by trucks. In addition, a ready source of water and a rapid method of filling the tank are necessary to achieve an efficient operation.

Vegetative plantings consist of sodding or sprigging which are often the cheapest and most effective methods for revegetation of critical areas. Sods from established areas can be cut and moved for use in critical areas such as waterways and terrace outlets. Young willow, alder or birch are also useful for sprigging but the material must be moved while it is dormant. In tundra, alpine and permafrost areas the thick vegetative mat of mosses, lichens and dwarf willows could be used to establish vegetative cover if put through a chopper or hydromulcher and put in solid contact with mineral soil at the proper time of year.

It is recommended that certified seed be used whenever it is available, as it guarantees germination and purity. *A Vegetative Guide for Alaska* is recommended for detailed instructions for scarification, seed treatment and inoculation. Simple seed mixtures are better than complex ones. Small seeds are more easily established than larger ones where seed is broadcast. In aerial seeding, heavy seeds fall directly to the ground whereas light seeds are often blown off course by wind. Mixtures containing a high proportion of annual species or rapidly establishing species can create internal competition for long-lived perennials. Excessive seeding rates can provide a quick cover but may create too much competition, especially on critical areas.

Three different processes of seed pelleting are described. However, these methods are expensive. Furthermore, the seed bulk and transportation costs are greatly increased and the results are no better than using clean seed. It is recommended that pelleting be used only for expensive seeds.

The best time of seeding is at the beginning of the longest period favourable to plant growth. In Alaska this is generally between May 15 and June 15. No permanent seeding should be made after August 10, excepting for annual grasses or cereals used for temporary cover to reduce erosion.

The best results in revegetation are achieved from methods that work with nature to re-establish native vegetation as rapidly as possible. The author suggests that no seeding should be made unless it has an 80% chance of success.

1. SCOTT, J.J.

2. 1976

3. Research and development priorities - surface mining reclamation in Alaska.

4. Prepared for the U.S. Department of the Interior, Bureau of Mines by J.J. Scott, Department of Mining, Petroleum and Geological Engineering, University of Missouri-Rolla, Rolla, Missouri. 10 p

5. Original

6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga

   b. Alpine, Southern Yukon, Northern Yukon, Southwestern Mackenzie, Central Mackenzie; Overburden, Roads, Tailings

7. This report constitutes the findings of a workshop involving the Alaska Mining industry and state and federal officials under a U.S. Bureau of Mines contract.

In the introduction to mining conditions in Alaska, it is noted that coal, gold, sand and gravel are mined and that mined lands in Alaska are normally worth more after they are mined based on their cost per acre. This is due mainly to the elimination of permafrost in the mining process. Vegetation is quickly re-established and the normal problems of ground settlement associated with permafrost are not present.

Geological conditions of Alaska and Yukon Territory are similar but development of mining properties are quite different as a result of different government attitudes. For example, many areas in Alaska have been withdrawn from mineral exploration and access is limited, whereas in the author's opinion the Canadian government has enhanced access in Yukon Territory by constructing railroads and providing incentives to mining.

The problems are broadly divided between those principally political and those principally technical. The latter are defined as environmental impact statements, baseline data and vegetation studies. The quality of environmental impact statements was queried on the basis of the value of the technical information and whether they are too speculative.

Baseline data are vitally needed on several subjects for the rational development of new projects: (1) water quality, especially the chemical and siltation aspects; (2) natural flooding conditions; (3) vegetation in the natural state; and (4) animals and the best conditions for them. Studies examining these factors need to be conducted in virgin areas unaffected by previous mining and the results compared with areas where

Continued ...

mining is in progress or immediately contemplated. The author indicates that vegetation is normally more lush on mined lands than in natural conditions, and this attracts wildlife to the area, providing good browse and habitat for an increased population.

Vegetation studies need to determine which species - particularly the best type of grasses - grow best on reclaimed land and in some cases how to prevent encroachment of natural species. For example, access roads to mineral or timber operations not maintained for a few years become impassable because of tree growth so that it is easier to construct a new road than remove the dense vegetation on the old one.

New mining systems are needed which include planning for the secondary use of the land along with reclamation prior to commencement of mining. One example is given; stackers on dredges might be re-designed to place the waste material from the placer in a more level manner which would reduce the cost of levelling.

1. SELNER, J.E.

2. 1973

3. Surface mine reclamation research in Alberta.

4. Alberta Lands and Forests, Alberta Forest Service, Land Use Branch, Edmonton. 50 p

5. Original

6. a. Alberta; Rocky Mountains

   b. Alpine, Southwestern Mackenzie, Southern Yukon; Overburden

7. This progress report describes part of the reclamation research conducted by the Alberta Forest Service in several different forests, of varying elevation, that have been disturbed by past industrial activity. The research was geared to seek solutions to these questions: (1) what are the most effective and economically acceptable methods of reclamation suitable for different ecological conditions in Alberta; and (2) what are the most difficult problems which occur during reclamation activities in the field?

As a result of a 1971 survey of old, abandoned and newly mined localities, it was found that the most frequent natural colonization on many sites was broad-leaved and coniferous tree species with grasses and legumes sometimes completely missing as a result of natural selection during primary succession. Reclamation research is therefore directed to reclamation by afforestation - using trees and shrubs.

In the field, the most difficult problems involve reclamation at high elevations, reclamation on steep slopes, reclamation on southern and western exposures and problems with nutrient deficiencies and plant chlorosis. Knowledge of reclamation in the alpine tundra zone is very limited. Research must determine the most successful technique for reclamation and the gradient limit for successful reclamation on steep slopes before regulations can be formulated. New methods for establishing and protecting vegetation on hot, dry exposures is another need that is being researched. Overburden is unable to hold nutrients and basic elements for tree growth over a long period of time so that by the second year after fertilization nutrient levels are equivalent to abandoned, sterile spoil piles, insufficient for vegetation to survive.

Research activities in 1973 focussed on planting poplar (*Populus balsamifera* and *Populus trichocarpa*) cuttings and rooted cuttings at Coleman in the Crowsnest Pass area and at Sterco in the Edson Forest. Evergreen research plots were established at three locations in the

Continued ...

Selner, J. 1973. Continued

Edson Forest and later at Tent Mountain and Grassy Mountain from seed derived at mid-elevations in the Hinton and Crowsnest forests. The desired seed from high elevations was not available. Species used were white spruce bare-root stock, white spruce in containers and lodgepole pine bare-root stock.

The poplars were attacked by fungus and aphids while rooting and gave unfavourable results necessitating a repetition of the research. Poplar is the most common and most successful species growing through primary succession on spoil piles in Alberta and use of poplar cuttings is the easiest and least expensive method of reclamation. Other methods to be tried in the future include planting one-year old poplar stems on two year-old roots and planting three year-old poplar roots without stems, both of which have been successful methods but are more expensive than use of cuttings. Plantings of non-rooted cuttings on western exposure spoil piles at York Creek resulted in total failure due to lack of moisture for successful sprouting.

Results from planting coniferous species on spoil piles at Sterco, Lovett and Coal Valley in the Edson Forest are extremely good with 83% of all species surviving vigorously. Results from the Crowsnest area are less favourable with 57% of all species surviving. Further mortalities were expected in the winter of 1973-74 so the total percentage of those surviving vigorously will be lower than these figures.

One plot at Luscar and one at Coal Valley were seeded to a nurse crop prior to planned afforestation if winter survival of this species is good. The nurse crop consisted of brome, Russian wild rye, alfalfa, yellow and sweet clovers and spring vetch treated with standard fertilizer. Soft surfaces showed better results than hard surfaces and best growth occurred in surface depressions where moisture conditions were better. The grasses showed partial sunburn after germination; the legumes survived better than the grasses, sweet clovers and alfalfa, and spring vetch did not progress well at all.

Seeding at Coal Valley confirmed that if soft and fine overburden is deposited on the surface of spoil piles during the mining process, successful reclamation can be accomplished very cheaply, for between $30 to $40/acre. Seeding at Grassy Mountain for grasses and legumes was a failure partly due to very low rainfall that summer. At Tent Mountain similar seeding saw a successful germination of legumes previously thought to grow very poorly at high elevations. This is in agreement with an earlier study at Fording River, British Columbia, which found that legumes grew satisfactorily at 5,500 ft and 6,700 ft.

Reclamation research conducted at higher elevations, such as Caw Creek Ridge at 6,500 ft, showed excellent growth of grass and legumes in the first vegetation period but a drastic reduction over winter occurred so that only native species and those similar to native species survived: Nugget Kentucky bluegrass, Polar brome, Arctared creeping red fescue, hard sheep fescue (*Festuca ovina* var. *duriuscula*), Erika creeping red

Continued ...

Selner, J. 1973. Continued

fescue and Reptans creeping red fescue. At Tent Mountain, similar plantings gave the same elimination of all species except fescues, bluegrass and timothy, which showed very limited progress. These successful species will be tested further.

Thirty-five photographs illustrate various aspects of the reclamation undertaken and the captions for these photographs emphasize several important points for reclamation. Correct timing is the most important condition for reclamation by afforestation on mined sites. It must be accomplished in early spring to use moisture provided by melting snow. Trees must be transported and planted immediately as any delay can cause higher mortality. Conifers are planted by hand into bigger holes than normal. Each tree is marked by a wooden stake and spacing is measured. Reclamation is more difficult on steep slopes; some trees may be buried by movement of unstable spoil. On southern exposures, pure coal overburden can create a desert-like microclimate hostile to trees so that a planting stake can provide sufficient shade for the tree to survive. Bare-root white spruce seedlings gave the best results on different spoils and lodgepole pine was second best and well adapted to dry and overheated pure coal strata. Mortality of evergreens was lower on spoil piles under protection of nurse crops and evergreens benefit from the nitrogen supplied by legumes.

1. SELNER, J.E.

2. 1974

3. Reclamation afforestation in the green zone of Alberta.

4. In: D. Hocking and W.R. MacDonald, Editors, Proceedings of a Workshop on Reclamation of Disturbed Lands in Alberta, Northern Forest Research Centre Information Report NOR-X-116, p 94-97

5. Original

6. a. Alberta; Canadian Taiga, Rocky Mountains

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. A 1971 survey by the Alberta Forest Service of abandoned and newly-mined coal locations in the non-agricultural zone of the province indicated that deciduous and coniferous trees were dominant on many abandoned sites and grasses and legumes were sometimes completely absent from the primary colonizers. Based on these findings, reclamation research is now partly directed to reclamation by afforestation.

The survey revealed that spoil banks had a great variability of natural invasion; one may revegetate naturally in 20 to 30 years, while another remains barren.

Experimental planting of broad-leaved and coniferous trees in different areas, elevations and exposure indicated: (1) *Picea glauca* was the species best able to survive on overburden, with *Pinus contorta* var. *latifolia* second best; (2) *Populus balsamifera, Populus tremuloides* and *Populus trichocarpa* are valuable for reclamation up to 5,000 ft; and (3) use of nurse crops can create favourable microsite conditions for better afforestation.

1. SHEARD, R.W.

2. 1976

3. Properties of slow-release fertilizers.

4. In: Proceedings of the Inaugural Meeting Canadian Land Reclamation Association, Crop Science Department, Ontario Agricultural College, University of Guelph, Guelph, Ontario, p 58-64

5. Original

6. a. Ontario; Eastern Forest

   b. Yukon and Northwest Territories; Overburden

7. Much research has been directed to slow-release fertilizers that would release small quantities of plant nutrients at a rate of release equal to the rate of uptake by growing plants. The objective of this research is to mimic microbiological breakdown of organic matter in soil. This could be achieved in two ways: (1) by using chemical compounds with slow dissolution properties; or (2) by physically coating fertilizer pellets with semi-permeable membranes.

Fertilizers normally contain nitrogen, phosphorus and potassium. However, a slow-release fertilizer containing all three does not exist because no slow-release form of potash exists. Bone-meal, a slow-release form of phosphorus, is limited because of high price, and rock phosphate is applicable only where pH is 5.0 or less. A pelletized, slow-release fertilizer that contains nitrogen, phosphorus and potassium does exist in the United States but high cost and availability make its use questionable.

1. SHELDON, J.C. and A.D. BRADSHAW

2. 1976

3. The reclamation of slate waste tips by tree planting.

4. Landscape Design 113:31-33

5. Original

6. a. England, Wales; British Forest

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. On some slate waste tips in Wales, Cornwall and the Lake District in England, isolated tree species can be found growing extremely successfully, with reasonable annual growth increments. Oak and sycamore are the most common species and in more moist areas birch *Betula pubescens* and *Betula pendula* occur.

Slate is an inert, very hard and durable rock which weathers very slowly. Tips several hundred years old appear much as when first formed except for lichen growth. An absence of fine shale at the surface prevents plant colonization. However, deep-rooted trees can establish and grow successfully. The establishment stage is critical until the roots penetrate into the underlying waste where moisture and nutrients are available.

Planting of trees on tips has several advantages: tree planting is an economic method of improvement and does not involve earth moving; trees improve the aesthetics of the landscape; and trees attract wildlife and accumulate litter to allow invasion of wild plants.

Site factors limiting tree establishment are: (1) drought conditions on the tip surface for much of the year restrict seed germination and establishment; (2) no source of nitrogen is present except that imported by rainfall or grazing animals; (3) grazing by animals; and (4) mechanical hazards to plants from the unstable tip slopes. Seed germination is hazardous except in extended wet periods. Species with large seeds (oak and sycamore) can produce tap roots rapidly because of nutrient reserves in the large seed. Direct planting of saplings resulted in a high mortality from either drought or leaching of nutrients in high rainfall areas.

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Sheldon, J.C. and A.D. Bradshaw. 1976. Continued

A research program was initiated to find a technique of planting which involved as few operations as possible on the readily erodible surfaces of the tip. Peat, because of its water-hold capacity and its potential to reduce leaching was used with slow-release fertilizer additions of magnesium ammonium phosphate (Enmag 5:24:10). The peat was lightweight and economical for use on difficult slopes and the slow-release fertilizer provided nutrients over a long time to counterbalance leaching. A minimum volume of 3.6 litres of peat was required for each 1 + 1 birch sapling. This volume of peat was enough for the first summer and yet small enough to encourage root growth deeper by the second summer. Slabs of slate were arranged around the peat pocket to increase the moisture catchment area.

For large-scale planting, the peat was mixed with fertilizer, limestone and wood cellulose to make a thick slurry which was then pumped by one operator into depressions in the tip. The advantages of this method are: the compost is moist and can be planted after two days settling time; a large number of holes can be filled by one operator reducing labour and traffic on a highly erodible surface; and the flowing slurry completely fills cavities between slate blocks and reaches the shale below.

Of the tree species tried, birch proved to be an excellent species for reclamation because of its low nutrient requirements, its ability to thrive in both dry and moist sites once established, and its rapid growth. This species also seeds well to help further colonization and its deciduous habit is an aid to litter buildup. Lodgepole pine (*Pinus contorta*) also did well but had poor ability to build up soils because its leaves are tough and resistant to rapid decay. Alder (*Alnus glutinosa*) was a very successful species which benefited from its own ability to fix nitrogen, thus overcoming the nutrient problem which exists in the shale. The authors suggest that interplanting of alder with other species would be most beneficial for improvement of the nitrogen level in the soil. Without alder, nitrogen deficiencies would require correction through fertilizer application.

The authors warn that the ultimate factor determining successful revegetation of such waste tips is the exclusion of grazing animals.

1. SHETRON, S.G. and R. DUFFEK

2. 1970

3. Establishing vegetation on iron mine tailings.

4. Journal of Soil and Water Conservation 25:227-230

5. Original

6. a. Michigan; Eastern Forest

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. The potential of iron tailings as a medium for plant growth was tested at the open-pit Republic Mine located on Michigan Peninsula. Tailings there consist of finely crushed bedrock of low plant nutrient status with pH values ranging from 7.8 to 8.1. The tailings ranged from loamy fine sand at the discharge point to silt at the point furthest from discharge. They varied in surface colour from weak red to dusky red and because of this colour the surface warmed rapidly during the day and cooled rapidly at night during the growing season. Water penetrated the tailings rapidly and they were subject to severe wind erosion.

The treatments consisted of: a commercially fertilized plot; a sawdust plus tailings mixture plot; a fertilized sawdust plus tailings mixture plot; and a control plot. Growth and survival of five grasses, two legumes and three tree species were evaluated for those four treatments. Species tested during the first season included:

Alfalfa	*Medicago sativa*
white clover	*Trifolium repens*
ryegrass	*Lolium multiflorum*
timothy	*Phleum pratense*
orchardgrass	*Dactylis glomerata*
black locust	*Robinia pseudoacacia*
jack pine	*Pinus banksiana*
red pine	*Pinus resinosa*

The fertilizer applied was premixed ammonium nitrate, triple superphosphate and murate of potash in a ratio of 1-3-3 (20-60-60 lb/acre) for legume-grass mixtures, and a 2-1-2 ratio (40-20-40 lb/acre) for grasses.

Continued ...

Shetron, S.G. and R. Duffek. 1970. Continued

The results showed that no decrease in pH was recorded after two growing seasons in any of the treatment blocks. More phosphorus occurred in the upper few inches of tailings of plots fertilized initially and repeated twice at the same rate, a fact attributed to the slow leaching of phosphate fertilizers.

The tailings were found to be interlaced with discontinuous, fine-textured layers at varying depths. Significantly higher concentrations of nitrogen and potassium were located in these fine layers than in the tailings above or below them. It was found that the fine-textured layers contributed substantially to vegetative growth. These layers acted as water and nutrient storage reservoirs throughout the growing season. Roots of herbaceous plants were found to be growing laterally when a fine-textured layer was encountered.

A 100% plant cover was achieved in the first growing season using legume-grass mixtures, orchardgrass, tall fescue and annual ryegrass with three fertilizer applications. With one fertilizer application growth was less for the same species, with only 30 to 40% cover. Timothy and bromegrass were used as nurse crops for white clover and Verna alfalfa. The two legumes did well on blocks fertilized only once, and actually supressed their respective nurse crops.

Growth of grasses and legumes in the control plots was poor with only 20 to 25% cover and an average height of 2 inches. In the plots with sawdust the grass and legume species suffered complete mortality shortly after germination, but in the sawdust plots supplemented with fertilizer a dense cover of alfalfa and clover was produced. The grass species in this latter treatment persisted only 2 to 3 weeks and then died. It was found that the sawdust benefited the plant growth for a short time but the mechanical disturbance of discing the sawdust into the tailings destroyed the fine-textured layers near the surface and therefore destroyed the water and nutrient reservoirs.

Survival rates of the trees planted varied from 20% in the blocks fertilized once to 92% in the control blocks. Of the three species, red pine had the highest average survival rate, followed by jack pine and black locust.

Wind erosion was common to all treatment blocks. In one instance, 4 1/2 inches of tailings were removed by wind erosion in a block of tree seedlings adjacent to some herbaceous vegetation. To combat this, oats strips were laid out; they trapped approximately 1,400 tons of windblown tailings during the second growing season.

It was calculated that 2 to 3 acres/hr were planted with a seed drill with no prior seedbed preparation (with the exception of the sawdust application). Trucking of sawdust proved to be expensive. The per acre cost for a grass or legume seeding, fertilized three times, at the time of writing was about $75/acre.

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Shetron, S.G. and R. Duffek. 1970. Continued

It is understood that the primary goal of vegetation stabilization is to quickly establish by economic methods a self-perpetuating plant community that stabilizes the tailings and enhances the aesthetics of the area. It was shown that this could be done, but an unanswered question is how long the plant community will perpetuate itself.

1. **SMITH, R.A.H. and A.D. BRADSHAW**

2. 1972

3. Stabilization of toxic mine wastes by the use of tolerant plant populations.

4. Transactions of the Institute of Mining and Metallurgy 81:A230-A238

5. Original

6. a. England, Wales; British Forest

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. An economic and permanent method of stabilizing toxic metal mine waste is needed to prevent pollution and to improve the aesthetic value of mined areas. Naturally occurring metal-tolerant plant species are a possible solution, through use of such plants as *Agrostis tenuis* and *Festuca ovina*, which in Britain grow on acid waste, or *Agrostis stolonifera, Festuca rubra* and *Deschampsia caespitosa*, which grow on calcareous material.

Mine spoils vary in metal content. Lead and zinc usually occur together and copper separately, but all three are known in some spoils. The most important variation is the presence or absence of calcium, most often occurring as calcium carbonate, which radically alters pH and the potential of waste as a plant growth medium.

The species listed above contain populations tolerant of high heavy metal concentrations and low macro-nutrient levels. A reclamation plan was developed for toxic spoils in Wales and England using seed of such species in conjunction with fertilizer amelioration. These tests showed that as long as fertilizer is given, the tolerant populations grow successfully. Ordinary commercial material of the same species grew for a short time but died within a year, usually as a result of drought. Metal-tolerant species root well and are much less susceptible to drought.

Metal tolerance of species is specific to individual metals, and different species also have preferences for particular calcium levels and acidity levels. For British conditions, three different grass species have been submitted for seed multiplication for specific site conditions so that populations of appropriate tolerances are available:

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Smith, R.A.H and A.D. Bradshaw. 1972. Continued

Festuca rubra (red fescue) - for calcareous lead-zinc wastes
Agrostis tenuis (bent grass) - for acidic lead-zinc wastes
Agrostis tenuis (bent grass) - for copper-contaminated wastes
Agrostis stolonifera - for calcareous lead-zinc wastes

The last species has poor seed production and is vulnerable to drought but could be valuable for hand planting in damp situations because it spreads readily by stolons.

A drawback of this approach is that use of metal-tolerant vegetation for grazing is not feasible since appreciable amounts of toxic metals enter the plant, even for metal-tolerant species. For long established swards, levels may rise to 0.4% metal content. However, this method is valuable for amenity improvement and for control of erosion.

The use of topsoil is not always feasible because of cost and availability, unless vegetation is required for use in agriculture or if it is required that the landscape be restored completely to its original appearance and use. Tolerant plant populations provide an important alternative approach to physical and chemical stabilization, and have the added advantage that if properly handled they could last indefinitely.

1. STAMP, L.D.
2. 1951
3. The reclamation of abandoned industrial areas.
4. Journal of the Royal Society of Arts, Volume C, No. 4863:97-114
5. Original
6. a. England; British Forest

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. Reclamation is considered important for economic and aesthetic reasons. Subsequent uses of derelict lands in Britain include industrial use, housing, recreation and nature reserves. Old quarries are of special importance as nature reserves for the particular native vegetation and wildlife that occupy these areas.

Revegetation of spoil banks from collieries has potential use as forests. The Midland Reafforestation Association which started its pioneer work in 1903 found that deciduous trees could better tolerate the smoky, soot-laden atmosphere of the early industrial sites than could the conifers. However, by 1951 the planted areas, using such species as alder, black poplar, sycamore, willow, wych elm, birch and ash, had become derelict from public abuse.

Suitable soil-forming material is needed for reclamation. Soil analyses, selection of fertilizer, knowledge of the crumb structure and correct selection of species involved are other requirements. Flat-topped tips of the old style are easier to reclaim but use up more land than the modern conical tips.

Restoration must be viewed as a long-term process and time must be allowed for settlement. A common mistake is to try to restore land to its former use immediately. Ten years is considered necessary for the land to consolidate.

Several questions are posed but not answered, with respect to soil handling. Should topsoil be stripped and stored? What happens to the crumb structure, humus content, earthworms, bacteria and other organisms when soil is stored? What happens to aerobic bacteria buried in a large mass of soil?

A problem with iron workings is that the overburden often consists of massive beds of limestone and sandstone which, after the ore is removed, are a waste of giant blocks often left as hill and dale formations. It has been found that trees will grow on such hill and dale formations better than on flat land providing the waste is not in large blocks.

1. STANLAKE, M.G., E.A. STANLAKE and D.S. EASTMAN

2. 1977

3. Reclamation for wildlife in southeastern British Columbia.

4. Paper presented to the Coal Industry Reclamation Symposium, Banff Springs Hotel, February 13-17, 1977, sponsored by The Coal Association of Canada. Unpaged

5. Original

6. a. British Columbia; Rocky Mountains

   b. Alpine, Southern Yukon; Overburden, Roads

7. This report is based on a 3-year study of ungulate use of reclaimed strip mines in southeastern British Columbia. Wild ungulate use of reclaimed areas increased annually over the 3-year period but remained unchanged in the surrounding natural areas. However, even after 3 years, undisturbed habitat was used 61% more than the most heavily used reclaimed habitat.

The authors made the following recommendations in relation to revegetation to encourage wildlife use of reclaimed areas:

1. During the mining of an area, "islands" of natural vegetation should be left wherever possible to provide not only a seed source for plants but also cover for wild ungulates. These "islands" should be planned for in the initial stages of the mining operation.

2. More field trials should be carried out on the suitability of native forbs and grasses for the reclaimed areas. In choosing native forbs and grasses, emphasis should also be placed on palatability and nutritive value to wild ungulates.

3. To enhance the reclaimed area for wild ungulates, more trees and shrubs, preferably browse species such as saskatoon and willow, should be planted.

4. To increase slope stability and also to encourage wildlife use at the beginning of the reclamation process, clumps of natural grasses, forbs and shrubs could be planted.

5. The influence of various application rates of different fertilizers on annual growth, seed production, nutrient content and utilization should be defined for reclamation plant species. This information could then determine the most effective way to hasten the reclamation process through fertilization.

1. STEWART, W.D.P.
2. 1967
3. Nitrogen-fixing plants.
4. Science 158:1426-1432
5. Original
6. a. World-wide

   b. Yukon and Northwest Territories; Overburden, Roads, Tailings

7. The biological agents of nitrogen-fixation in the world are legume-rhizobium bacteria associations, blue-green algae, non-leguminous nodulated plants of both angiosperms and gymnosperms, plants with leaf nodules and free-living nitrogen-fixing bacteria, and possibly some fungi, actinomycetes and yeast. Ninety percent of the total contribution of the estimated 100 million tons of nitrogen produced per year is believed to be of biological origin. In agricultural ecosystems, nodulated legumes are the dominant nitrogen fixers with bacterial symbionts of rhizobium. The nodules are regarded as specialized ecological niches that provide essential microenvironmental conditions and specific metabolic products so that the bacteroids (the enlarged non-motile bacteria which result in infected cells) can fix nitrogen. Iron and molybdenum appear to be required for symbiotic nitrogen fixation and molybdenum is routinely added to many agricultural soils where nodulated legumes grow. The amounts added are small, as little as 70 gm/ha or 1 oz/acre.

Among the 13 genera of root-nodulated angiosperms are *Alnus, Shepherdia* and *Arctostaphylos*. These woody perennials are characteristic pioneer plants of areas low in combined nitrogen where they have a competitive advantage. Crocker and Major (1955) reported the abundance of *Alnus* species in recently deglaciated areas of Alaska linking it with nitrogen fixation.

Blue-green algae are most abundant as free-living nitrogen-fixing organisms. Generally, the more extreme the physical conditions, the more blue-green algae are likely to be present, provided light, water and carbon dioxide are available.

1. STOVER, J.C.

2. 1973

3. Mulching in Alaska.

4. In: 1973 Alaska Revegetation Workshop Notes, Co-operative Extension Service, University of Alaska, p. 27-33

5. Original

6. a. Alaska; Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon Coast, Northern Yukon, Alpine, Southern Yukon; Overburden, Roads, Tailings

7. Mulches are used to provide raindrop protection, inhibit erosion, moderate climatic extremes (especially diurnal extremes), add strength to soils at or near the shear failure point, and to increase or decrease surface temperatures. Mulches provide temporary or permanent protection while helping a permanent vegetation cover to develop.

Factors that must be considered when evaluating mulches include: steepness of slope; presence or absence of moisture; aesthetics; freeze-thaw cycles; impermeable or permeable treatment; thermal influence and particular use (such as ditch and channel lining or check dam protection).

Not all mulches are advantageous. Fibreglass and other inactive materials do not decompose, wood chips deprive the soil of nitrogen, and white-coloured mulches reflect too much light. In addition the mechanisms amd influences of chemical binders are not completely understood.

Straw is one of the best mulches for erosion prevention on gentle slopes. It also moderates climatic variations which helps vegetation to establish. Many methods have been used to stabilize the straw: partial burial or complete burial, stakes and twine, and bonding liquids. Emulsified asphalt is used as a bonding agent at approximately 1 ton/acre (222 gal) and can be applied simultaneously with seed and fertilizer. Better results are achieved when the bond is applied after seeding to avoid coating the seed. The Alyeska Pipeline project planned to use straw mulch (1 1/2 to 2 tons/acre) with the bonding liquid polyvinyl acetate (PVA), a non-toxic liquid. The latter is mixed as 1 gallon PVA in 100 gallons of water and this mixture is applied at the rate of about 500 gallons/acre. Seed and fertilizer may be applied after the emulsifier to control natural erosion on newly constructed slopes, which would be later seeded for permanent erosion prevention.

Continued ...

Stover, J.C. 1973. Continued

Wood excelsior is used for mulch on slopes that exceed 2:1, where the tensile strength of the mulch is significant. One brand, American Excelsior, consists of wood excelsior on 4 ft-wide nylon net, and is comparable to straw mulch with a bond as far as erosion control and revegetation success is concerned. The author recommended pinning the net with ample slack to accommodate all surface irregularities. The wood excelsior is initially white, but ages to brown and is not noticeable once grass is 2 to 2 1/2 inches tall. Wood excelsior may be sprayed with coloured emulsified asphalt to increase soil temperatures. The wood excelsior can also be laid lengthwise along a cut top to prevent underwash or headward erosion.

Fibreglass is the most durable mulch. It is applied with an air compressor and special nozzle, sometimes with a tack coat to prevent the fibreglass from blowing away. One plan calls for fibreglass mulch on cuts above ice-rich soils. All material over 2 inches diameter is cleared by hand from the cut face. Then 300 fibres/acre of fibreglass are applied by hand, weaving it into the existing vegetation and tying it into the vegetation mat to strengthen it and create a one-piece insulative mat as the ice melts underneath. Possibly 5 years will be needed to melt to a point of stability.

The PVA mentioned above is a recent soil stabilizer. It can withstand freezing but requires a 45° F temperature for the chemical reaction that makes it a crust or binder. Crusts are used on porous soils for stability; a semi-permeable membrane is created which traps water vapour. PVA is best for binding sand, or soils which are erodible on slopes or waterways. For use with silt, clay or loess, a wetting agent is necessary. After application, PVA is normally clear but can be whitened by adding titanium dioxide or blackened by adding lamp black. PVA is not suited for traffic areas because of breaking or cracking. The Alyeska Pipeline Service Company plans to use PVA for ditch liner and pond treatment to aid revegetation, for dust control, wind erosion control, and thermal erosion control.

1. STRANG, R.M.

2. 1973

3. Studies of vegetation, landform and permafrost in the Mackenzie Valley: some case histories of disturbance.

4. Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development. Report No. 73-14. 49 p. plus tables.

5. Original

6. a. Mackenzie Territory, Yukon; Canadian Taiga, Canadian Tundra

   b. Southwestern Mackenzie, Central-Mackenzie, Mackenzie Delta Region, Yukon Coast, Northern Yukon; Roads

7. This report is a result of a 1972 examination of soil and vegetation at about 200 sites where disturbances have occurred in the Mackenzie Valley and northern Yukon. Tabular data on the natural plant community, the disturbance (kind, season, elapsed time since disturbance), and the resulting ground cover after disturbance are presented for 19 disturbed sites near Fort Simpson, 27 near Wrigley, 22 near Fort Norman, 17 near Sans Sault Rapids, 15 near Fort Good Hope, 15 near Fort McPherson, 15 near Old Crow, and 44 in the Inuvik area.

In relation to revegetation of ice-rich soils, the author noted that serious damage resulted from re-use of stabilizing old roads or seismic lines. The wet soil and re-colonizing vegetation, including *Carex* spp., *Eriophorum* spp., *Ranunculus gmelini*, and *Petasites* spp., seemed to be very intolerant of disturbance, so that a second round of disturbance was causing severe degradation.

The author identified several knowledge gaps in relation to revegetation and reclamation of disturbed sites in the north:

1. With reference not only to pipelines but also to highway construction and other kinds of development, we do not yet know how best to re-establish a vegetation cover on disturbed sites so as to restore the negative thermal regime;

2. Where winter exposure of a frozen layer is unavoidable, an insulating layer is needed during the subsequent thaw season. We need to ascertain what materials best serve this need and, at the same time, provide a suitable seedbed for rapid re-colonization by natural or artificial seeding;

3. Where a slippage has occurred we need to be able to restabilize the site quickly. No practical work to develop a suitable technique has yet been attempted.

1. SUTTON, R.K.
2. 1975
3. Why native plants aren't used more.
4. Journal of Soil and Water Conservation 30:240-242
5. Original
6. a. United States

   b. Yukon and Northwest Territories; Overburden, Roads, Tailings

7. The obstacle to the use of native plant species in the private sector is their lack of supply. Field collection on a large scale is not practical because it is difficult to ensure viable plants and to confirm their origin (for altitude and latitude) and uniformity. There is also potential damage to fragile environments where collection takes place.

Commercial nurseries do not have native plants in sufficient quantity or diversity because there has been a lack of demand, supply problems, low uniformity in stock, and ignorance about growing and storage. For large scale reclamation, land managers are unable to find certified, regionally adapted native seed.

Although written in reference to the United States, the content of this article has general relevancy. It points out that the various ecotypes contribute to the diversity and stability of a natural landscape. A species may have within it an ecotype with genetic differences that relate to a narrow environmental range.

The use of native species is still hampered by unresolved problems regarding degradation of collection sites, visual harmony achieved in planting areas, species adaptation to the planting sites, and maintenance of planted material.

1. SYNCRUDE CANADA, LIMITED

2. 1975

3. Revegetation: species selection - an initial report.

4. Syncrude Canada Limited, Edmonton. Environmental Research Monograph 1974-3. 47 p

5. Original

6. a. Alberta; Canadian Taiga

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Tailings

7. This monograph is the first public report of the Syncrude revegetation program which is planned as a long term (up to 30 years) effort directed to reclaiming and rehabilitating the land disturbed during oil sands extraction using native species as far as possible. To establish a stable plant community, it was felt that the natural sequence of vegetation succession offered the best example. To this end, the general plant communities of the area were surveyed as were naturally and artificially revegetated areas occurring in the Athabasca Tar Sands area such as cutlines, pipeline rights-of-way, roadsides and surface mined areas. Cutlines have the least disturbance; topsoil was not disturbed so that rapid natural revegetation occurred. Natural revegetation was slower on sites where topsoil and litter were removed and erosion became a problem. Vegetation on these sites consisted of a few introduced weeds and native pioneer species such as fireweed (*Epilobium angustifolium*) and wild strawberry. Severe soil disturbance occurs over a pipeline trench leaving relatively infertile parent material at the surface. Left to revegetate naturally, these areas have as the most common species: bluejoint, slender wheatgrass, bluegrasses, fireweed, wild rose, wild strawberry, wild raspberry, field horsetail, marsh horsetail and common yarrow. Legumes present were wild vetch and occassionally pea vine with weeds such as dandelion, sow thistle and Canada thistle.

On roadsides where seeding had taken place, smooth brome, red fescue and timothy were the most important grasses with sweet clover, alsike clover, white clover and red clover as the important legumes. Where seeding had not occurred and natural revegetation had taken place the most common groundcover was field horsetail, willows, fireweed, sedges, reed grasses, wild strawberries, wild vetch and sweet clover.

Revegetation of the tar sands areas to be surface mined presents special problems because the tailing sands are low in plant nutrients and have a

Continued ...

Syncrude Canada, Limited. 1975. Continued

very low water-holding capacity. The loose, single grained structure of the sands mean that they are very susceptible to erosion by both wind and water, and a plant cover is essential to prevent this erosion. Application of fertilizer can overcome the low fertility but a plant cover is still necessary to recycle the nutrients to prevent their leaching from the soil. Without such plant cover continuous fertilizer application would be necessary to maintain a groundcover of sufficient density to prevent erosion. Experiments by Great Canadian Oil Sands Limited (Massey 1972) and by Environment Canada (Lesko 1974) indicated that seeding with commercial forage species onto untreated tailing sands was not successful to produce an effective groundcover, even with application of fertilizer. Some method of increasing the water-holding capacity of this sand was required and peat was mixed into the top 6 inches of tailing sand. Contour trenching before seeding also proved effective as an aid to grass establishment. Some native species, for example sweetgrass (*Hierochloe odorata*) or Houghton sedge (*Carex houghtonii*) may be able to establish on tailing sand without special treatment.

Lesko (1974) determined after two growing seasons that the grass species which successfully established themselves were: crested wheatgrass (*Agropyron cristatum*), pubescent wheatgrass (*Agropyron tricophorum*), latiglume wheatgrass (*Agropyron latiglume*), streambank wheatgrass (*Agropyron riparium*), smooth brome, redtop (*Agrostis alba*) and timothy. What is not known for these species is how long they will be able to maintain themselves. Great Canadian Oil Sands was able to establish good stands of introduced forage grasses and legumes using a Brillion grass seeder and mixing seed with peat in the tailing sand (Massey 1972). For more consistent results this method was preferred over hydroseeding.

Pot tests were carried out to determine species response to various soil types and time to germination. The results indicated that in some cases soil type affected the time required for germination and the ecotypic differences in response within a species also became evident. Two examples are given: the first is *Alopecurus* spp. which grew fairly well in silt peat but not well in tailing sand or tar sand. In contrast, *Agropyron trachycaulum* grew equally well in the pot tests in all tested soil types. This latter species may be of great value in the tar sands area. However, the demonstration of ecotypic differences within a species makes it important to select the correct species for reclamation and to select the best lines within that species for the particular area of concern.

A program of seed production is presently in progress for both native and naturalized species. The plant response and suitability will be determined by evaluation of the effects of a particular environment on disease resistance, and quality and quantity of seed produced. Reliable methods for handling and growing these materials must be determined, and seed production programs should be established for carefully selected species.

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Syncrude Canada, Limited. 1975. Continued

A glossary of 22 terms is provided, including a clear distinction in the definition of reclamation, rehabilitation and restoration. Reclamation is defined as the return of a disturbed site to a condition where the original organisms or similar organisms can inhabit the site. Rehabilitation means that land is returned to a stable ecological state according to a land use plan that does not contribute to further environmental deterioration. Restoration means that site conditions, including topography, will be returned to essentially the same state they were in prior to the disturbance. Revegetation is the provision of a vegetative cover to a disturbed site.

1. TAYLOR, K.
2. 1976
3. Environmental alteration and natural revegetation at Discovery Mine, Northwest Territories, Canada.
4. University of Alberta, Edmonton. M.Sc Thesis. 190 p
5. Original
6. a. Mackenzie District; Canadian Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mainland Tundra, Southern Yukon; Overburden, Tailings

7. The conclusion of this thesis, after examination of the Discovery Mine at 63 10 N, 113 50 W in the Northwest Territories, was that natural revegetation is a slow process which will require some assistance for the tailings and waste to be revegetated. The degree of assistance required will depend on the permitted time for an acceptable level of reclamation.

Relatively inexpensive, unassisted long-term recovery (more than 30 years) may seem desirable for remote northern development sites. However, this is regarded as impractical because of the time required for erosional equilibrium to occur before plant colonization can commence. Planning is necessary for the short-term (up to 10 years) and the medium-term (20 to 30 years) to prevent industrial blight areas and because northern areas are increasingly accessible to the public.

Evaluation of the conditions at Discovery Mine revealed that natural revegetation will not occur in the short-term and that revegetation in the medium-term will be effective only in certain favourable locations. A plan with yearly evaluation of progress is necessary to achieve that objective. Although, since 1976, all land use operations in the Northwest Territories are governed by review and inspection procedures, the author felt that more emphasis must be placed on monitoring impact and on planning of reclamation. For example, plans should show the form of final reclamation and the steps taken during the life of the project to facilitate that objective.

Several measures are suggested to stimulate the revegetation of tailings at the Discovery Mine. These are: 1) a need to experiment with revegetation (species and methods) while a mine is in operation to determine toxic components, optimum or minimum levels of nutrients, the need for irrigation, if any, and the necessity for shelter; 2) the use of bogs or other natural depressions for infilling with tailings, as a way to decrease drought problems on tailings to be revegetated; 3) restrict the

Continued ...

Taylor, K. 1976. Continued

depth of tailings, where feasible, to less than 50 cm to enable colonizing species to root into the buried organic cover below the tailings; 4) make organic debris available at regular intervals by bulldozing the vegetation into windrows before tailings are deposited; 5) placement of organic material such as straw, brush or peat on the surface of tailings to provide surface stability, nutrients, shelter and moisture; and 6) use of locally treated sewage where possible for effective fertilization and creation of surface stability.

Several species that colonized the tailings at Discovery Mine stood out for their ability to revegetate naturally: *Equisetum* spp., *Eriophorum angustifolium* and *Carex aquatilis* adapted to moist locations; *Epilobium angustifolium* and *Hordeum jubatum* on dry and some exposed locations; and the shrubs *Salix* sp., *Betula* sp. and *Alnus crispa*.

In summary the critical components of northern reclamation programs are foresight, an understanding of the local environment, and a willingness to work within the restraints of the environment.

1. TAYLOR, K.G. and D. GILL

2. 1974

3. Environmental alteration and natural revegetation at a mine site in the Northwest Territories, Canada.

4. In: J. Tomlinson, Editor, Proceedings of the International Conference on land for waste management, Department of Environment and National Research Council, Ottawa, p. 16-25

5. Original

6. a. Mackenzie District; Canadian Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Mainland Tundra, Southern Yukon; Overburden, Tailings

7. Revegetation of tailings at the Discovery Gold Mine, 84 km northwest of Yellowknife, is patchy and limited to areas where the depth of tailings is shallow enough (30 to 40 cm) for plant roots to penetrate into the original ground surface or where some form of added organic matter (animal droppings, garbage, rotted wood and campfire ashes) has provided a foothold for colonizing plants. Such pioneer species are foxtail barley (*Hordeum jubatum)*, fireweed (*Epilobium angustifolium*) and slough grass (*Beckmannia syzigachne*) in areas of added organic matter. These same species plus *Equisetum arvense, Equisetum fluviatile, Equisetum sylvaticum, Eriophorum angustifolium* and *Carex aquatilis* are the pioneers in areas of shallow tailings. Most species reproduce through creeping rootstalks. Shrubs of alder (*Alnus crispa*), willow (*Salix* spp.) and birch (*Betula glandulosa*) and one tree species (*Betula papyrifera*) are also present, usually at the interface between tailings and undisturbed areas. Where tailings were a few centimetres thick, lichens, some mosses and Labrador tea grew on the tops of protruding hummocks and cottongrass, horsetail and sedge grew in the depressions.

There appears to be little difference in the rate of natural revegetation in various portions of the tailings, despite differences in age. Horsetail, fireweed and cottongrass were growing in a tailings gully where tailings were deposited two years previously, but other older tailings remained barren.

Factors which influence and limit natural revegetation on the tailings are: 1) change of microhabitat in ways that prevent regrowth of the original bog species; 2) access to organic material either at the surface or buried; 3) soil acidity and associated metal toxicity (some tailings samples had a pH as low as 3, which triggers toxic levels of metals such

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Taylor, K.G. and D. Gill. 1974. Continued

as aluminum or manganese); 4) drought; 5) surface crusting which limits plant establishment; and 6) instability of the top few centimetres of soil by wind or water erosion.

Four measures were suggested to assist natural revegetation of tailings: 1) development of a plan for tailings disposal with orderly creation of disposal areas which would enable the establishment of an equilibrium favourable to plant colonization; 2) use of adequate permanent diking or natural depressions or basins to prevent tailings erosion and instability; 3) planned addition of organic matter by bulldozing vegetation into windrows before the tailings are deposited (and limiting the depth of tailings to 30 cm), by placement of organic material such as straw, brush or peat on the surface, or by use of locally treated sewage for fertilization and surface stabilization; and 4) establishment of test plots during the mining operation to determine threshold levels of acidity and nutrients, and the expected physical and chemical changes through weathering processes.

1. THIRGOOD, J.V.

2. 1972

3. Planning the reclamation project.

4. In: Environmental Management - The Mining Scene. The Reclamation of Disturbed Land areas, Centre for Continuing Education, University of British Columbia, Vancouver, B.C. 8 p

5. Original

6. a. British Columbia; Coastal, Interior, Rocky Mountains

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. The author defined land reclamation as the restoration of a fertile and pleasing landscape with a future use for forestry, range, agriculture, wilflife, watershed or recreational values. It means that rock waste must be recognized as the skeletal soil on which future land use depends and much of the success of reclamation depends on the way in which the extractive phases of mining are conducted.

Proper planning and the establishment of suitable institutional frameworks for efficient reclamation procedure can reduce deleterious effects and expenditure of time, effort and money. Reclamation involves three distinct phases: (1) prior land use planning including an inventory of land and water resource before mining; (2) physical operations to achieve a suitable topography; and (3) natural or assisted revegetation and subsequent management of the reclaimed land.

Within a given climatic region, reclamation success is determined by: the geological formation (the value of different strata for plant growth); the mining technology (particularly disposal of refuse and restoration of the surface); the methods of improvement for subsequent land use (these include revegetation and species established); and the intensity of further land management. Of these, only the geological formations are outside human control.

To a great extent the final land use potential and aesthetic appeal are a function of the configuration, structure, texture, hydrologic properties and suitability to plant growth of the land surface. The physical phase of reclamation is basically an engineering problem and the planning of mine refuse disposal is critical to minimize final contouring and re-handling. Stockpiling means double handling and immediate placement of overburden to a final resting place is a preferred method providing there is segregation of material not suitable as a plant medium. Sterile or toxic materials need burying and planning should provide for special placement of topsoil.

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Thirgood, J.V. 1972. Continued

The success of reclamation is determined by the progress toward the final objective, not by the success of a pioneer crop accompanied perhaps by heavy fertilization. Reclamation is concerned with the permanent productivity of the reconstituted site and it can also be directed to a different form of land use than the pre-mining one. One benefit of mining is that it can provide access to and increase the area available for public recreation but this must be weighed against mass public access to fragile wilderness areas.

1. THIRGOOD, J.V.

2. 1976

3. Reclamation research at a mine site in north coastal British Columbia - a five-year progress report.

4. In: Proceedings of the Inaugural Meeting Canadian Land Reclamation Association, Crop Science Department, Ontario Agricultural College, University of Guelph, Guelph, Ontario, p. 47-57

5. Original

6. a. British Columbia; Interior

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. Reclamation on the Kitsault Molybdenum Mine on the north coast of British Columbia (50 24 N, 129 25 W) is in the initial stages, but several insights are reported here. A key factor is the rugged, mountainous country and the typical coastal climate with high precipitation well distributed throughout the year.

The mine was in production from 1967 to 1972, followed by a period of disuse that has permitted some observations on natural revegetation possibilities. It is clear that considerable disturbed areas in this coastal zone will revegetate naturally. It is also hoped that natural processes will revegetate the rock dumps, based on the evidence of revegetation of natural rock slides. On one area reserved for long-term study in 1972, one plant of ryegrass (*Lolium perenne*), one patch of moss, a small group of *Rubus* spp. and one *Epilobium* stem constituted the total revegetation. It is speculated that revegetation will be more easily achieved through slope modification than through attempts to vegetate steep unmodified banks.

In seeding trials begun in 1970 and assessed in 1974, distinct differences were apparent between various seed mixtures in speed of establishment, survival and total leaf production. In this study area, commercial grass mixtures can be grown on unweathered fragmented rock with the addition of fertilizer or organic material. Fertilizer and peat applications, when applied separately, give significantly better plant cover but together are not as productive. Organic material is not essential for successful seeding. Mixtures with legumes perform better than those without. Birdsfoot trefoil, which grew after a slow start, favourably influenced grass stands. An appreciable accumulation of organic matter can occur in the first year with a full stand of grass.

Continued ...

Thirgood, J.V. 1976. Continued

The author suggested that the long-term benefits of revegetation may be related to the provision of conditions that allow reversion to an early natural successional stage of vegetation establishment, rather than establishment of a grass sward.

Planting of bare-root tree stock directly into waste rock in 1970 proved that lodgepole pine was the most vigorous tree species under all conditions. The other species - hemlock, amabilis fir and sitka spruce - lacked vigour and were chlorotic. These trials also confirmed the desirability of growing trees, especially lodgepole pine, in association with nitrogen-fixing species.

Reinvasion of alder, willows, and western hemlock has taken place in the Kitsault townsite. Growth is rapid and minimal treatment will be necessary to reclaim the area that was completely stripped of all vegetation originally. A situation somewhat similar exists at Anyox, 20 miles from Kitsault, where smelter fumes (which ceased in 1935), and later fire, destroyed the vegetation.

1. THIRGOOD, J.V. and M.D. MEAGHER

2. 1972

3. Progress in reclamation research by mining companies in British Columbia during 1971.

4. The Forestry Chronicle 48:308-311

5. Original

6. a. British Columbia; Coastal, Interior, Rocky Mountains

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. This survey of the progress in reclamation in British Columbia was based on an examination of 28 reports submitted by mining companies to the Minister of Mines and Petroleum Resources as required by the Mines Regulation Act 1969 and the Coal Mines Regulation Act 1969.

The authors analysed approaches to ground preparation, revegetation, fertilization, seeding methods, subsequent treatment, organization of field operations and costs. The following areas were identified as continuing problems: (1) a lack of awareness of procedure, such as the use of fertilizers before revegetation was attempted; (2) in some situations a vegetative cover can only be maintained by heavy and repeated fertilization because of leaching which makes the practice doubtful; (3) how far is the principle of compatibility - that reclaimed land should complement the surrounding land use pattern - to be applied? This question is raised in connection with the use of grass cover instead of trees in reclamation of forested areas; (4) plant supply and obtaining suitable provenances is a continuing problem that is insoluble at the individual company level and emphasizes the need for governmental or cooperative industry activity; (5) shrubs as reclamation species are often overlooked, partly because too little is known of their growth characteristics, requirements and seed treatments, such as scarification; (6) more valuable results could be obtained from field trials if the trials were designed and replicated to permit finer testing of the various effects and interactions. The example mentioned is determination of phytotoxic levels of metal in leaf samples in revegetated areas designed to serve as wildlife feeding areas.

Costs reported in this survey varied considerably. The modal figure was $180 to $200/acre when ground preparation, fertilizer, seed, inspection and refertilization were involved, in 1971. One company with a specialist reclamation group further defined costs for that year as follows:

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Thirgood, J.V. and M.D. Meagher. 1972. Continued

hand seeding - $22 to $32/acre; machine seeding, ground preparation and cost of seed - $113/acre; hydroseeding of roadcuts - $120/acre; contract planting of tree seedlings - $180 to $250/acre; and landscaping (machine levelling and ground preparation, tree planting, grass seeding and fertilization) - $167 to $215/acre.

Many companies were concerned with "instant green" and only a few identified long-term post-mining land use objectives. The authors considered this a major deficiency in reclamation planning.

Seed mixtures varied from "standard" formulations of range and pasture grasses that were used on a wide range of environmental conditions to tailored mixes for specific sites.

1. UNITED STATED DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE
2. 1972
3. A vegetative guide for Alaska.
4. U.S. Department of Agriculture, Portland, Oregon. M7-N-22612. 50 p
5. Original with excerpts
6. a. Alaska; South Coastal, Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra

   b. Yukon and Northwest Territories; Overburden, Roads, Tailings

7. This guide, a revision of an earlier bulletin entitled *Grasses for Alaska* (1970), provides a common source of information on planting and management procedures for forage production and revegetation of disturbed sites in Alaska. It is the result of teamwork between several agencies and institutions in Alaska to provide a unified approach to the wide range of conditions in that State. Periodic updatings are envisioned as new information becomes available.

The guide is organized in six major sections: an introduction; culture and management for establishing grasses and legumes; soil and site groups; seeding recommendations; lawn and turf seeding; and woody and herbaceous ground coverings.

One section on grasses and legumes outlines the basic information and steps to revegetate an area, and is reproduced here in entirety as published in this report.

1. Soils - The upper 12 inches of the soil should consist of a loamy material and be able to hold at least 3/4 inches of water to permit the establishment of good vegetative cover. The soil must be porous enough to allow root penetration, and tillable for good seedbed preparation. On construction sites such as highways, airports, and subdivisions, topsoil has often been removed. If a good turf is desired, it may be necessary to replace the soil material. Where soil has been entirely removed, at least 4 inches of loamy material should be added before seeding.

2. Seedbed Preparation - Proper seedbed preparation is an important factor in establishing a good stand of grass. In many areas, incorporation of dead vegetation and organic matter by intensive cultivation is necessary to get a satisfactory seedbed. After tilling and packing, the seedbed should be firm; a heel imprint should barely show after walking over the ground. The soil should be weed-free and

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moist. When the seedbed is well prepared, the amount of seed needed will be less and success of the planting will be greater. On steep sloping land or construction sites where tillage implements cannot be used, the soil should remain in a rough condition. Slopes should be prepared as well as possible and roughened with construction equipment so that the broadcast seed will have a chance to remain in place long enough to germinate and produce a stand.

3. Seed Specifications - Certified seed should be used whenever it is available. Germination and purity tests should be used to determine the proper seeding rates for each grass or legume variety. Legumes should be scarified if necessary and inoculated with the proper strain of nitrogen-fixing bacteria before seeding. Use only northern strains of grasses and legumes.

4. Time of Seeding - For best results seedings should be made from May 15 to June 15. Successful seedings can be made later in the summer but grass and legumes should not be seeded later than August 10 to avoid winterkill. Annual ryegrass or cereal grain can be seeded until September 1 to secure a temporary cover to reduce erosion. The area should then be seeded to a perennial grass the next spring.

5. Seeding Methods

a. Drill - A grass drill is the best method of seeding on nearly level to sloping land, but the preferred method will depend on slope and conditions of planting site. Very small seed must be seeded not more than 1/4 to 1/2 inch deep. A packer should be pulled behind the drill unless the equipment already has a packer combination. On steep slopes where drilling is not feasible, the hydroseeder method is preferred. When applying seed, fertilizer or mulch materials with the hydroseeder, use not more than 100 to 150 lb of solids per 100 gal of water. It is best to apply seed or seed and fertilizer first, to ensure seed contact with the soil, followed by the mulch. Fertilizer can be added to the water slurry as long as the material is used within a few hours after mixing, preferably when the soil is already moist.

b. Hydroseed - Hydroseeder Operation (1,000 gallon tank)

(1) Seeding - (2 acres)	Seed 40 - 100 lb Fertilizer - 800 - 1,200 lb Water - 1,000 gal
(2) Mulching - (1/2 acre)	Fiber mulch - 500 - 600 lb Water - 1,000 gal

If necessary to seed, fertilize, and mulch in one operation, each 1,000 gallon load should cover 1/3 acre and the mixture for each load would be as follows:

Seed 7 - 17 pounds	Mulch 333 - 400 pounds
Fertilizer 135 - 200 lb	Water 1,000 gallons

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U.S. Dept. of Agriculture, Soil Conservation Service. 1972. Continued

Caution must be taken to add seed and fertilizer first and to mix these thoroughly in a tank at least 1/3 full of water before adding mulch.

c. Broadcast - If the broadcast method of seeding is used, rates of seed application should be twice that recommended for drilling.

d. Sprigging - Sprigging (planting a shoot, root or sprout of a plant) and sodding (covering with sections of sod) are special methods which are costly, but necessary for some grasses. Sodding and sprigging may be preferable to seeding in critical situations.

6. Fertilization - Fertilization is important to ensure a good growth of grass. Grass should be fertilized each year for best results.

The general recommendations for fertilizer are 60 lbs N (nitrogen) - 60 lb P_2O_5 (phosphate) - 60 lb K_2O (potash) per acre the first year and a maintenance application of 30-60-30 each ensuing year on construction sites. On cropland, use 60-60-60 the first year and 120-60-60 each ensuing year. Where soil testing service is available, fertilizer application should be based on soil tests. Some possible combinations of commercially available fertilizers to obtain the indicated amounts of N, P, and K are:

60-60-60	300 lb of 10-20-20 plus 100 lb of 33-0-0 or 300 lb of 10-20-10 plus 100 lb of 33-0-0 plus 50 lb of 0-0-60
120-60-60	300 lb of 10-20-20 plus 300 lb of 33-0-0 or 300 lb of 10-20-10 plus 300 lb of 33-0-0 plus 50 lb of 0-0-60
30-60-30	300 lb of 10-20-10.

Many other combinations are possible. For best results, at least one-half of the nitrogen added should be in the form of nitrate. Urea is not generally recommended because of its slow availability in Alaska soils.

7. Maintenance - Grass seedings must be kept moist after seeding and until the grass has reached a height of 1 to 2 inches. If possible, supplement water should be supplied especially during prolonged periods of drought while grass is becoming established. Areas planted other than for cropland may be cut for hay or silage if the situation warrants cutting. Critical sites may need water disposal structures, some reseeding or sodding, and maintenance applications of mulch and fertilizer.

8. Mulching - Mulching is important in establishing vegetation on steep construction sites or other critical areas. A mulch cover will help hold moisture, protect the soil from erosion, hold seed in place and keep soil temperatures more constant. It should be applied uniformly by mechanical means or by hand after seeding. Common types of mulching material used in critical-area plantings are hay, small grain straw, straw-asphalt, wood fibre, mulches, peat moss, gravel and jute matting. Grass seed straw, or native bluejoint hay, cut when seed is about

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U.S. Dept. of Agriculture, Soil Conservation Service. 1972. Continued

mature, often contains viable seed and is excellent for mulching. Some bare soil should still be visible through a straw mulch. Mulching is necessary on steep and critical areas, but is expensive and not always necessary to establish grass stands on favourable sites. Very early spring applications may retard the rate at which soils may warm up.

9. Annual Seedings - Annual ryegrass (*Lolium multiflorum*) is recommended for a quick catch on burned or critical areas for erosion control. Seedings at rates of 10 to 25 lb/acre should be made before August 1 for best results. Plan on seeding to perennial species the following spring. Annual ryegrass is also recommended for seeding with a perennial grass mixture to control erosion until the perennial grass becomes established.

Section III of this guide describes the six soil and site groups of Alaska. Each group is defined according to soil texture, natural drainage, and depth of substrata which restrict most plant roots. In addition, for each group the major soil limitation, engineering classification and available water holding capacity are indicated. These soil groups are:

Group 1 - Soils and sites with few limitations.

Group 2 Soils and sites with limitations due to low water holding capacity.

Group 3 - Soils and sites with severe limitation due to very low water holding capacity or steep slopes.

Group 4 - Soils and sites with moderate limitations due to excess moisture.

Group 5 - Soils and sites with severe limitations due to excess moisture.

Group 6 - Soils and sites consisting of wet peat materials.

In Section IV, seed and fertilizer recommendations are indicated on a map that shows climatically determined geographic areas. Once the soil group in a geographic area is determined, then seeding and fertilizer recommendations are developed using the table provided in this book. Each climatic region is divided into the six soil groups with corresponding listings of the different mixtures for revegetation of highly erosive or disturbed sites and species for cropland use. Because of the great detail of these tables, it is recommended that anyone interested in revegetation should obtain a copy of this text.

In the case of the arctic area, where no commercial seed is available for native species, the instructions are to revegetate highly erosive or disturbed sites by spreading freshly cut native cottongrass, sedges or

Continued ...

U.S. Dept. of Agriculture, Soil Conservation Service. 1972. Continued

other native tundra sod vegetation on the area. This material should be packed well and fertilized as indicated by soil tests.

From the recommendations given for the interior of Alaska for highly erosive or disturbed sites, two examples are selected:

Group 3 - Soils and sites with severe limitations due to very low water-holding capacity or steep slopes. Soils are well or excessively drained, very shallow or steep, droughty and include construction sites, road cuts and fills, and disturbed and compacted sites. Shallow soils have < 10 inches loamy material over gravel, sand or bedrock. Water-holding capacity is < 3 inches. On deep soils, for example those high in silt, erosion hazard is high.

Mixture or species in order of preference	Variety name in order of preference	Drill seeding rate lbs/acre
1. Smooth brome	Polar or Manchar	8 or 15
Hard fescue	Durar	5
2. Crested wheatgrass	Nordan	5
Hard fescue	Durar	5
3. Streambank wheatgrass	Sodar	15
4. Smooth brome	Polar or Manchar	15 or 10

Yellow and sweet clover may be added to these mixes at 5 lbs/acre

Group 5 - Soils and sites with severe limitations due to excess moisture, representing a wide range of soils generally wet throughout the growing season as the result of slowly permeable materials, high permafrost table, slow surface runoff or seepage. Soil depth is more than 20 inches and may have up to 16 inches peat on the surface.

Mixture or species in order of preference	Variety name in order of preference	Drill seeding rate lbs/acre
1. Creeping foxtail	Garrison	10
Kentucky bluegrass	Nugget or Merion	5 or 5
White Dutch or Alsike clover	-	3
2. Creeping foxtail	Garrison	10
White Dutch or Alsike clover	-	3
3. Timothy	Engmo	6
Kentucky bluegrass	Nugget or Merion	5
White Dutch or Alsike clover	-	3

The authors indicate that the permafrost condition common to these soils will normally return to the surface if grass is grown for more than 5 years.

Continued ...

U.S. Dept. of Agriculture, Soil Conservation Service. 1972. Continued

The section on loam and turf seeding emphasizes the importance of proper preparation of a firm seedbed and maintenance by fertilizer application and mowing. The section on woody and herbaceous ground coverings indicates that at present a limited number of both native and exotic plants are commercially available as seeds, starts and cuttings ready to plant. However, much research is needed to determine the best means of propagation and utilization of these materials.

One appendix lists the land capability classification for Alaska and another contains a list of the common and scientific names of grasses and legumes, herbaceous ground covers and woody ground covers. A third appendix lists 16 grass species and indicates their site adaptations, plant characteristics and management requirements. The same is done for five legumes (alfalfa, red clover, alsike clover, sweet clover and white dutch clover). To give just one example, smooth brome is adapted to moderate soil texture, has good drought resistance, fair wetness and flood tolerance, high fertilizer requirement, tall height growth, and very poor acidity tolerance. Recommended varieties are Polar and Manchar. Smooth brome has good seedling vigour, high yield potential, long longevity, a sod root system, high compatibility, high palatability, moderate recovery rate (after cutting), high seed production, high winter hardiness, multiple use and a minimum stubble height of 3 inches. Similar information is provided for all the other species listed in the appendix tables.

1. VAARTNOU, H.

2 1974

3 Establishment and survival of groundcover plantings on disturbed areas in Alberta. Progress Report 4. Soils.

4. Alberta Department of Agriculture, Edmonton, Alberta. 14 p.

5. Original

6. a. Alberta; Grasslands, Canadian Taiga, Rocky Mountains

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. In this fourth report, vegetation (plant communities and selected species) is related to a group of soil factors and climate, and soil texture is examined in more detail. The soil properties studied included pH, conductivity, sulfate, free lime, organic matter, sodium, potassium, phosphorus and texture. Soil samples were collected from roadsides and pipeline and powerline rights-of-way in Alberta.

Major differences in plant communities along the rights-of-way studied were correlated with the amount of disturbance created and the climatic zone of the specific site. Roadsides experienced the greatest disturbance, including seeding to agronomic species which created a plant community different from the adjacent native species. Pipeline rights-of-way are intermediate disturbances and powerline rights-of-way are the least disturbed in terms of plant community composition. In forested areas, the degree of difference for powerlines is related to the density of the treecover removed.

Soils with free lime present are most common along roadsides, less so for pipelines and least for powerline rights-of-way. The majority of soils showed a pH range favourable to plant growth with the roadside areas possessing the highest percentage of strongly basic soils, a reflection of the amount of disturbance and topsoil removal. Soils in the higher sodium ranges were present more in the roadside samples and least in the powerline samples. The reverse is true of the lesser sodium amounts (1 to 25 ppm range). The greater proportion of roadsides exhibited low organic matter content, a direct result of the amount of subsoil and parent material exposed by excavation and cutting for highway construction. This is also the reason why roadside areas possess the larger amounts of free lime.

Continued ...

Vaartnou, H. 1974. Continued

Relating plant communities to soil properties is tentative and is based on indications of which species are more tolerant of a wide range of the above-listed soil properties. Phosphorus levels measured are below that recommended for field crops, indicating that most Albertan native species should be adapted to low phosphorus in the soils. In addition, few soils are acid, but species more common on basic soils than on neutral soils included *Agropyron cristatum, Cirsium arvense,* and *Hordeum jubatum.* On neutral soils, common species are *Epilobium angustifolium, Koeleria cristata, Rosa* spp. and *Vicia* spp. *Bromus inermis* was more common on high pH soils, but it is felt that no special seed mixture is required for high pH soils in Alberta; one designed for neutral soils is adequate.

The major difference in plant communities occurred for soils with or without free lime. No trends towards increasing or decreasing abundance of species occurred with increasing free lime. In general, introduced species and weeds which are more common on disturbed sites increase with free lime present. Native species on undisturbed sites appear to decrease with free lime present. The presence of free lime is strongly related to the degree of mechanical disturbance and the effect of subsoil and parent materials. The lack of species response to increasing free lime suggests the presence of free lime is less important than the mechanical disturbance.

With increasing sodium content, only three weed species increased in abundance: *Agropyron repens, Hordeum jubatum* and *Sonchus arvensis. Agropyron trachycaulon* showed little change with increased sodium content. Some species decreased in abundance with increased sodium (*Bromus inermis, Koeleria cristata, Medicago sativa, Epilobium angustifolium, Rosa* spp. and *Vicia* spp.). High sodium soils have poor physical structure which is improved by severe mechanical mixing.

There is a need to find species suitable for undisturbed high sodium soils. *Agropyron trachycaulum* may be useful in revegetation of high sodium soils based on the data gathered, and possibly saline tolerant grasses such as *Puccinillia* and *Distichlis.*

Based on the data the only species more abundant on coarse and very coarse textured soils were the shrubs *Elaeagnus commutata* and *Rosa* spp., and the herb *Epilobium angustifolium.* The low water holding capacity and fertility of coarse textured soils makes the establishment and survival of vegetation difficult on such soils. The majority of species tested in this study are less abundant on such coarse textured soils. No special problem is envisaged with fine textured soils for the Alberta area. *Phleum pratense, Trifolium hybridum* and *Trifolium pratense* were found to increase in abundance with increasingly fine textured soils. *Poa* spp., *Taraxacum officinale* and *Trifolium repens* were more common in the medium and fine-textured soils.

Continued ...

Vaartnou, H. 1974. Continued

All roadside areas were of low organic content but it is not possible to say if climate of the soil zone or organic content governed plant community structure on the two rights-of-way.

Results regarding potassium showed that species increasing in abundance on soils low in potassium were mainly introduced species: *Festuca rubra, Taraxacum officinale, Phleum pratense, Rosa* spp. and *Trifolium pratense*. Species decreasing in abundance with decreasing potassium were all native species (*Bouteloua gracilis, Hordeum jubatum, Koeleria cristata* and *Stipa* spp.) excepting *Agropyron cristatum*. A large number of species did not appear affected by the amount of potassium in the soil. No data are intended on biomass production with various levels of potassium.

Additional research is planned to learn which other soil properties and which soil organisms are significant to revegetation projects. Recommendations for the use of species used in this report appear in the final report (1974).

1. VAARTNOU, H. (Editor)

2. 1976

3. Revegetation research. A progress report on work accomplished in 1975.

4. Sponsored by Alberta Agriculture, Alberta Environment, Alberta Transportation, and Alberta Oil Sands Environmental Research Program. Unpublished report. 350 p

5. Original

6. a. Alberta; Grasslands, Canadian Taiga, Rocky Mountains

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. A detailed provincial survey was started in 1973 to evaluate revegetative growth on newly disturbed areas. The major conclusion of the 1973 work was that revegetation of moist, well-drained areas presented no real problem. However, for more difficult areas, it became apparent that native species or naturalized landraces offered more chance of success. The 1974 work focussed on native species suitable for revegetation in Alberta, and the 1975 season was a continuation of this work. In the summer of 1975 it was possible, for the first time, to collect a reasonable amount of seed from native legumes and shrubs.

A large part of this report is devoted to a description of 56 revegetation test sites located in the aspen parkland, short grass prairie, boreal forest, and mountain areas of Alberta. Most of these revegetation test sites are on fairly steep slopes and many are on poor soil because previous work had indicated that these are the kinds of sites where revegetation problems will arise. With few exceptions these test sites have been hand planted in rows 36 inches apart, with the space between plants in each row also 36 inches. Fertilization of these sites has been minimal or nil based on the reasoning that species that need constant fertilization have little use in revegetation work.

Each site that was planted in 1975 has information on: location, soil properties, time and method of planting, moisture conditions at time of planting, detailed meteorological data, list of species planted at the site, and the first year's evaluation of the site. In future years, more detailed evaluations will be carried out, including information on winterkill and increase in ground cover through spreading by rhizomes.

Continued ...

Vaartnou, H. (Editor). 1976. Continued

Revegetation test sites in the boreal forest zone, relatively close to the Northwest Territories include:

Site 24, High Level	(58 30 N, 117 00 W);
Site 42, Rainbow Lake	(58 10 N, 119 25 W);
Site 45, Indian Cabins	(59 50 N, 117 05 W);
Site 46, Fort Vermilion	(58 11 N, 115 45 W);
Site 47, Keg River	(57 48 N, 117 38 W).

Reports by other authors in this report give details on soils analyses from the revegetation test sites (H. Feddema), seed technology study (G. Simonson), testing of grasses on various soil types (K. Yamanaka), testing of legumes on various soil types (N. Warrington), study of micro-organisms associated with seeds and seedlings (P. McPherson), and a preliminary survey of the Alberta oil sands area - bryophytes and lichens (P.W. Stringer).

Because most shrub seeds exhibit some type of dormancy which prevents immediate germination, the use of shrub seeds in revegetation can only be considered after some knowledge of these dormancies is available. Some species with potential use in the north that have been tested to date include: *Prunus virginiana*, *Arctostaphylos uva-ursi*, *Symphoricarpos occidentalis*, *Cornus stolonifera*, *Amelanclier alnifolia*, *Dryas drummondii*, *Elaeagnus commutata*, *Rosa* sp., *Shepherdia canadensis*, and *Vaccinium vitis-idaea*.

The testing of grasses on various soil types included trials with tailing sand from Yellowknife. *Poa palustris* was the only species that managed to grow reasonably well on fertilized tailing sand. *Agropyron trachycaulum* and *Festuca rubra* survived but grew poorly. There were no germination difficulties in either the fertilized or unfertilized tailing sand from Yellowknife, but growth stopped 1 or 2 weeks after germination in the unfertilized tailing sand. All legumes grew very poorly on the Yellowknife tailing sand. *Lathyrus* and *Hedysarum* survived in planting trials on this sand, but *Vicia* did not. The problem with the Yellowknife tailing sand may be due to the high salt content (conductivity 5.2 mmhos), or possibly due to the high sodium and sulphate content. There is also a fairly high potassium content and more was added in the fertilizer. This might account for the reduction of growth in the fertilized treatment. Experiments are still in progress with *Astragalus americanus*, *Hedysarum sulphurescens* and *Oxytropis campestris* growing on the Yellowknife tailing sand.

One part of this study is focussing on non-leguminous nodule-bearing genera in Alberta (*Alnus*, *Elaeagnus*, *Shepherdia*, *Dryas*, *Arctostaphylos*). The author stresses that the factors controlling revegetation by nodule-forming species must be studied. A number of problems may be encountered in establishing legumes: failure of the seed to germinate, no nodulation, ineffective nodulation, nutritional deficiencies essential to nodule formation, and plant competition. The presence of effective *Rhizobia* in the soil or on the seed must first be discovered as this will lead to the possibilities for inoculation or cross inoculation. The same types

Continued ...

Vaartnou, H. (Editor). 1976. Continued

of problems will be encountered for non-legume establishment. The determination of effective *Actinomycetes* in the soil or seed is the first step but inoculation will probably not be as simple as in legumes since little is known or understood about this process.

In revegetation studies absence of suitable vesicular-arbuscular mycorrhizae could be of initial importance in revegetation of sub-surface soils or soil that has undergone an extraction treatment such as will be the case in oil sands extraction processes.

1. VAARTNOU, H. and G.W. WHEELER

2. 1974

3. Establishment and survival of ground cover plantings on disturbed areas in Alberta.

4. Alberta Department of Agriculture, Plant Industry Laboratory, Final Reports of Phase I, Edmonton. 48 p

5. Original

6. a. Alberta; Grasslands, Canadian Taiga, Rocky Mountains

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. The purposes of this study, started in 1973, were to provide basic information needed for revegetation of disturbed areas such as roadsides and utility rights-of-way in Alberta. The first phase of the study, reported here, was a survey of existing vegetation on disturbed areas. This phase of the work included identification of native vegetation which may be used for revegetation on rights-of-way, roadsides, erosion control and surface-mined areas. Seeds of native plants for testing were also collected during the study and particular attention was given to the problem of weed infestation and weed control on reclaimed areas.

Separate progress reports were prepared for vegetation along roadsides, pipeline and powerline rights-of-way, and some strip mining areas. A fourth progress report related the vegetation to some important soil properties. The report annotated here is a synthesis of information from the previous four progress reports. Only those revegetation recommendations that relate to the boreal mixed-wood and the foothills and mountain zones of Alberta are annotated here. Most of the report is a list of grasses, legumes and shrubs suggested as candidates for revegetation. For each listed species there is information about its natural occurrence, general growth form and recommended use for revegetation. Specific recommendations on the revegetation potential of some species for the boreal mixed-wood, foothills and mountain regions of Alberta, and which also occur north of 60°, are summarized below:

Agropyron trachycaulum - grows well on many areas including coarse-textured soils, high pH, high free lime, and high sodium soils; very important species for initial groundcover on disturbed areas; some ecotypes useful for tar sands revegetation and others very resistant to northern diseases;

Agrostis gigantea - has performed well on tar sand tailings and establishes a good ground cover quickly;

Agrostis scabra - an important species for future study of various ecotypes in the boreal forest region;

Continued ...

Vaartnou, H. and G.W. Wheeler. 1974. Continued

Alopecurus pratensis - one of the most disease resistant grasses in northern areas and possibly very useful for reclamation north of 55° N;

Arctagrostis arundinaceae - a common grass in permafrost areas and definitely useful for reclamation north of 58° N;

Bromus inermis - does not do well on high sodium soils;

Bromus pumpellianus - ecotype selection and testing needed before recommendations can be made;

Calamagrostis canadensis - handling of its seed needs study before it will be feasible for reclamation; difficulties of handling and the ease with which it establishes itself on disturbed areas suggest that this species should not be used in seed mixtures;

Calamagrostis inexpansa - the Fort McMurray ecotype, from sandy soils, might be useful for reclamation of tailing sands and waste dumps;

Calamovilfa longifolia - one of the few species able to provide a ground cover for stabilizing pure sands but selection of ecotypes needed for use in northern areas;

Deschampsia caespitosa - selection of disease and drought resistant ecotypes required before usefulness for reclamation can be determined;

Elymus innovatus - ecotype selection needed to obtain disease resistant clones for reclamation in semi-shaded grey wooded soil areas;

Festuca brachyphylla - this native of rocky slopes and summits should be useful for high altitude plantings where other fescues are not present;

Festuca ovina - selected ecotypes would be very useful on light sandy soils such as tailing sands in the Fort McMurray region; other areas would include those mined for heavy metals or polluted by sulphur;

Festuca rubra - susceptibility to disease reduces its longevity; some varieties with longer rhizomes which are adapted to coarse sandy soils and resistant to local diseases would be useful if seed becomes available;

Glyceria pulchella - might be useful for seeding wet areas in the boreal mixed-wood region but more information on its agronomy, disease resistance and establishment is required;

Hierochloe odorata - common in low meadows and sometimes in recently disturbed areas, so may be useful for light, moist soils in the boreal and foothills regions;

Phleum alpinum - may be useful for revegetation at high elevations;

Phleum pratense - if to be used for revegetation, a selection of ecotypes resistant to diseases and adapted to various habitats is necessary.

Poa alpina - one of the best grasses for high elevation reclamation of wildlife range and other disturbed areas;

Poa compressa - requires more testing but could be very suitable for revegetation of poor soils;

Continued ...

Vaartnou, H. and G.W. Wheeler. 1974. Continued

Poa palustris - one of the primary invaders of disturbed soils and should be included in seed mixtures for rapid groundcover, but requires further testing for local disease resistance;

Poa pratensis - one of the most effective grasses for nearly all soil types and environmental conditions in northwest America, but requires ecotype selection based on resistance to snow mold;

Puccinellia distans - may be important for the reclamation of alkaline soils, but further testing and selection is required;

Astragalus canadensis - may be a useful legume for the boreal mixed-wood and foothills regions;

Hedysarum alpinum - this deep-rooted legume is one of the most promising species for future seed mixtures for reclamation in northern areas as well as foothills, however testing of ecotypes in various environments is required;

Lathyrus ochroleucus - unlikely to do well on high sodium or coarse textured soils;

Medicago falcata - could be one of the best legumes for reclamation in boreal mixed-wood regions;

Medicago sativa - does well on high pH soils that are fine to medium textured (a variety with a loose, rhizomatous habit and resistant to local diseases is required for reclamation purposes);

Trifolium repens - useful on high lime soils but not for high sodium or coarse textured soils; if a proper disease resistant variety is chosen it may be useful in moist environments;

Vicia americana - an important native of the boreal mixed-wood region that grows well on high pH and high lime soils but not on high sodium soils;

Amelanchier alnifolia - research to find ecotypes suited to various ecological regions is needed;

Arctostaphylos uva-ursi - likely to be most useful on coarse-textured soils in the boreal mixed-wood region and in the mountains and foothills; methods of using seed to establish plantings must be developed before this species can be recommended for revegetation;

Arctostaphylos rubra - more study is needed for use of this species in the boreal mixed-wood region; it could prove useful on moist soils in the north and at higher elevations in the mountains;

Cornus stolonifera - before this species can be recommended for revegetation practical methods of using the seed to establish plantings must be developed;

Dryas drummondii - this species may be good for reclamation of dry, rocky areas but its establishment and management will need to be studied first;

Juniperus horizontalis - a useful shrub on light soils in northern and western Alberta but more study is needed on seeding and early management if it is to be used for revegetation;

Continued ...

Vaartnou, H. and G.W. Wheeler. 1974. Continued

Prunus pennsylvanica - a very useful species for improving the aesthetic value and wildlife habitat in northern regions but germination of seed and early management requires further study;

Rosa acicularis and *Rosa woodsii* - would be useful on high pH and high lime soils and also good on coarse-textured soils;

Symphoricarpos albus - may be useful for slope stabilization, wildlife habitat improvement and aesthetic enhancement but more information is required on its establishment and management;

Vaccinium myrtilloides - may prove useful for revegetation but more information is required on its establishment.

Vaccinium vitis-idaea - more information is required on establishment and maintenance before consideration as a revegetation species;

Viburnum edule - more information is necessary before useful recommendations can be made.

This species list is preliminary and will be modified as more information becomes available. The authors stress the importance of ecotypic variations, especially where a species is listed for several different zones within Alberta.

1. VAARTNOU, H. and G.W. WHEELER

2. 1975

3. Establishment and survival of ground cover plantings on disturbed areas in Alberta.

4. Alberta Department of Agriculture, Plant Industry Laboratory, Botany Section, Edmonton. Site Establishment 1974 Progress Report. 190 p

5. Original

6. a. Alberta; Grasslands, Canadian Taiga, Rocky Mountains

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Most of this report is devoted to descriptions of 34 revegetation test sites that were established in Alberta in 1974.

The criteria used for selection of species for revegetation included: intended use, disease resistance, type of root system, adaptability to specific soil properties, cover protection, adaptability to local environments, competitive ability, aesthetic value, and food value for wildlife.

For three ecologically distinct areas within the boreal zone (Boreal Mixedwood, Alluvial Lowland around Lake Athabasca, and Jackpine Sand Plain near Lake Athabasca) the following potential revegetation species were singled out:

Boreal Mixedwood grasses for well-drained sites - *Agropyron dasystachyum, Agropyron subsecundum, Elymus innovatus, Bromus pumpellianus;*

Boreal Mixedwood grasses for moist sites - *Poa palustris, Calamagrostis canadensis;*

Boreal Mixedwood legumes - *Lathyrus ochroleucas, Lupinus arcticus, Vicia americana;*

Alluvial Lowland grasses for well-drained sites - *Agropyron smithii, Agropyron trachycaulum, Poa pratensis, Poa palustris, Agrostis gigantea, Festuca rubra, Elymus innovatus, Hierochloe odorata, Arctagrostis arundinacea, Alopecurus pratensis, Phleum pratense;*

Alluvial Lowland grasses for moist sites - *Glyceria pulchella, Deschampsia caespitosa, Calamagrostis inexpansa, Agrostis scabra, Phalaris arundinacea;*

Continued ...

Vaartnou, H. and G.W. Wheeler. 1975. Continued

Alluvial Lowland high salinity grasses - *Poa ampla, Puccinellia distans, Agropyron yukonense;*

Alluvial Lowland legumes - *Trifolium hybridum, Hedysarum alpinum, Medicago falcata;*

Jack Pine Sand Plain grasses - *Elymus innovatus, Calamagrostis inexpansa, Festuca ovina, Agrostis scabra, Festuca saximontana, Hierochloe odorata;*

Jack Pine Sand Plain legumes - *Astragalus canadensis, Astragalus cicer, Astragalus crassicarpus.*

Shrubs of the boreal zone listed as potential revegetation species were: *Arctostaphylos uva-ursi, Arctostaphylos rubra, Elaeagnus commutata, Vaccinium myrtilloides, Vaccinium vitis-idaea, Symphoricarpos albus, Rosa acicularis, Rosa woodsii, Prunus pennsylvanicus, Prunus virginiana,* and *Amelanchier alnifolia.*

The authors expected that preliminary recommendations on the revegetation potential of these various candidate species could be made within two years, but more complete recommendations may require up to 10 years of study.

1. VAN CLEVE, K.

2. 1972

3. Revegetation of disturbed tundra and taiga surfaces by introduced and native plant species.

4. In: B.H. McCown and B.R. Simpson, Co-ordinators, The impact of oil resource development on northern plant communities, 23rd AAAS Alaskan Science Conference, Institute of Arctic Biology, Fairbanks, Alaska, p 7-11

5. Modified author's abstract, with additions.

6. a. Alaska; Central Alaska Taiga, Alaskan Tundra

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Yukon Coast, Northern Yukon, Alpine, Southern Yukon; Overburden, Roads

7. The first four paragraphs below are a modified version of the author's abstract.

This report summarizes three year's work which emphasized field testing of hardy introduced plant species and other techniques which might be utilized to stabilize ground surfaces in arctic and subarctic Alaska. Field trials of selected hardy grass species have shown considerable success at 6 of 8 transect sites from Fairbanks to Prudhoe Bay. Revegetation with introduced species at selected disturbed surfaces in the Prudhoe Bay and Happy Valley-Sagwon areas did not show as much success as revegetation trials at more southerly sites. Short growing season, cold soil temperatures and the dry nature of disturbed sites may be responsible for the reduced rate of growth by introduced species at the northern sites. Regevetation of droughty sites encountered on road berms, drilling pads or campsites may require additional watering or mulching with organic matter to help retain moisture.

Considerable success has been obtained with selected annual and perennial grasses at sites south of Happy Valley including high altitude areas at Galbraith Lake and Anaktuvuk Pass. With respect to sites south of Happy Valley, annual ryegrass, Arctared fescue, Durar hard fescue, meadow foxtail, Icelandic poa, Nugget poa, and *Agropryon trachycaulum* were generally rated excellent for revegetation potential. A number of additional species including reed canarygrass, Climax timothy, Engmo timothy, creeping red fescue and *Deschampsia caespitosa* were generally rated good for revegetation potential.

Continued ...

Van Cleve, K. 1972. Continued

In general, best growth response was obtained with higher phosphate fertilizers (8-32-16) applied at the rate of 400 lb/acre. Laboratory tests with creeping red fescue and Climax timothy grown in selected study soils tentatively indicate that a 2 to 1 ratio of phosphorus to nitrogen would also be a favourable nutrient combination to apply in field trials. Additional application of fertilizer should be made the year following seeding to avoid nutrient deficiencies and maintain rapid growth rates. Additional seed applications may be necessary in selected areas to ensure rapid surface stabilization.

The importance of revegetation of disturbed surfaces by invading native species has been observed at several study sites. Depending on the degree of surface disturbance, root stocks remaining in the soil may provide an important source of inoculum for recovery of native species in disturbed sites. In addition, transport of seed to disturbed areas from adjacent natural areas may assist long term surface stabilization. Transplanting of native tree seedlings in disturbed sites may provide long term surface stabilization in more accessible areas south of the Brooks Range.

The criteria used to evaluate revegetation potential of individual plant species are: (1) ability to survive several growing seasons; (2) adequate reproductive potential (seed and vegetative); (3) root and top production; and (4) rapid plant development and adequate cover development.

The cold soil temperatures influence nutrient status partly by retarding the rate of mineral weathering and decomposition of organic matter on and in the soil, and partly because these cold dominated soils contain insufficient amounts of nutrients critical for plant growth. The highest concentrations of nitrogen were found in surface soil organic layers. Therefore, methods that retain some original organic matter are beneficial to nutrient levels of disturbed areas. The study soils were found potentially adequate in P and N but their availability was restricted by the slow chemical weathering.

Additional work is needed at Prudhoe Bay and Happy Valley, the two northern sites, to define the best planting time, the best rates of seed application and rates and combinations of nutrients applied in fertilizers. More time is needed to evaluate growth and survival of the introduced species to determine their long term success.

1. VAN CLEVE, K., L.A. VIERECK and R.L. SCHLENTNER

2. 1971

3. Accumulation of nitrogen in alder (*Alnus*) ecosystems near Fairbanks, Alaska.

4. Arctic and Alpine Research 3:101-114

5. Authors' summary with additions

6. a. Alaska; Central Alaska Taiga

   b. Southwestern Mackenzie, Southern Yukon; Roads

7. (1) A study of biomass and nitrogen accumulation was conducted in even aged alder ecosystems developing on the Tanana River flood plain near Fairbanks, Alaska.

   (2) After a rapid increase in mean annual biomass increment during the first 5 years of ecosystem development, the increment shows a slower but steady increase from 5 through 20 years. The productivity of these ecosystems occupies an intermediate position compared with the productivity of forest ecosystems in other geographic regions.

   (3) The mean annual rate of nitrogen build-up is rapid during the first 5 years of ecosystem development but decreases with ecosystem age to 20 years.

   (4) Rates of addition of N in these alder ecosystems are equal to or greater than those reported for alder by other investigators. Periodic additions of N may occur by flooding. These additions are probably small compared with the additions of N by symbiotic fixation.

The average annual increment for a 20-year period was 4,734.5 kg/ha/yr of biomass and 156.4 kg/ha/yr of nitrogen. Maximum rate was recorded during the 0-5 year period: 6,162.7 kg/ha/yr of biomass and 361.6 kg/ha/yr for nitrogen.

Dominant components of the herbaceous vegetation were *Equisetum pratense* and *Equisetum variegatum* which made up 10% of the cover in the 5-year-old ecosystem. This cover increased with increased stand age so that by 20 years a conspicuous feature was the *Equisetum pratense* dense cover with less conspicuous *Moehringia lateriflora* and *Calamagrostis canadensis*.

1. VIERECK, L.A.

2. 1966

3. Plant succession and soil development on gravel outwash of the Muldrow Glacier, Alaska.

4. Ecological Monographs 36:181-199

5. Portions of author's summary, with additions

6. a. Alaska; Southern Alaska Taiga

   b. Alpine; Overburden, Roads

7. The following numbered items are part of the author's summary on plant succession and soil development on gravel outwash of the Muldrow Glacier in Alaska:

1. Plant succession and soil development are described for a series of five stands on glacial outwash adjacent to the McKinley River in an alpine tundra region of the Alaska Range in Mount McKinley National Park.

2. Based on estimates of the time of retreat of the ice at the end of the late Wisconsin glaciation, the age of the climax stand is estimated to be 5,000 to 9,000 years.

3. The vegetation development progresses from that of scattered mat plants with isolated willow and *Shepherdia* shrubs to a closed grassy meadow interspersed with small but dense clumps of willow shrubs. Birch shrubs and a thick moss mat begin to form under the willow shrubs and eventually replace them. The low shrub birch forms a continuous and even stratum underlain by a thick moss layer of *Hylocomium splendens* and *Pleurozium schreberi*. The final stage, the climax tundra, consists of low shrub birch and ericaceous shrubs interspersed with *Eriophorum vaginatum* tussocks growing through *Sphagnum* and other mosses.

4. The soil undergoes progressive changes from the initial coarse gravel outwash through the four successional stands to the climax condition. Surface soil becomes slightly finer in texture with time, probably through the addition of wind-blown material rather than through physical weathering. Organic material, mostly in the form of decaying mosses, is added in a thick layer at the surface and small amounts are added to a depth of 10 cm in the later succession stages. Nitrogen is added to the soil, primarily through nitrogen-fixing organisms associated with legumes, *Dryas* and *Shepherdia*. The pH is altered from 8.0-8.4 of the original outwash to 4.4 in the climax tundra soil.

Continued ...

Viereck, L.A. 1966. Continued

5. Due to the insulating effects of the vegetation, especially the thick moss stratum, permafrost has developed or has risen near the surface in the climax stand. The permafrost layer prevents the downward loss of moisture through the soil, creating a wet condition suitable for the development of sphagnum mosses and sedge tussocks.

The vegetation of the pioneer stage consists mostly of mat and clump species which reach only a few centimetres in height. *Dryas drummondii* and *Dryas integrifolia* have the highest cover. Clumps of legumes such as *Astragalus tananaica, Astragalus nutzotinensis, Oxytropis gracilis* and *Hedysarum mackenzii*, have a cover of approximately 20%. Apart from the legumes there are no other important herbs. A few shrubs are present - three willow species and infrequently *Shepherdia canadensis* and *Potentilla fruticosa*.

The meadow areas are characterized by large homogeneous mats of *Elymus innovatus, Festuca altaica* and *Poa* sp.

Initial invasion of the gravel outwash is by light-seeded species and legumes, with *Dryas drummondii* perhaps the most important and one of the first. The seeds of this species lodge in fine material where they establish and the plant spreads radially. Other light-seeded species are *Epilobium angustifolium, Crepis nana,* balsam poplar and willow species. Some plants flourish at one stage, die and become favourable sites for the establishment of other plants or mosses.

The nitrogen-fixing species are greatly reduced in the meadow stage. However, nitrogen fixed by these organisms apparently continues to be transported down into the 5-, 10-, and 20-cm layers through the late shrub stage.

The greatest change in pH takes place during the period between the pioneer and meadow stages, probably as the result of rapid leaching of calcium carbonate. Subsequent lowering of pH is at a slower rate with little increase at depths greater than 10 cm.

1. VIERECK, L.A.
2. 1970
3. Forest succession and soil development adjacent to the Chena River in interior Alaska.
4. Arctic and Alpine Research 2:1-26
5. Original
6. a. Alaska; Central Alaska Taiga

   b. Southwestern Mackenzie, Southern Yukon; Roads

7. The river floodplains of interior Alaska offer an excellent opportunity for study of forest succession as it relates to soil development and permafrost, and to document changes evident in the soil and vegetation that occur with time.

Succession begins with colonization of exposed gravel and silt bars by light-seeded herbs and shrubs, primarily *Salix* and sometimes thinleaf alder (*Alnus incana*). The two willows (*Salix alaxensis* and *Salix pseudocordata*) and alder are pioneer species that are intolerant of shading.

During the second stage, balsam poplars grow rapidly and form pure stands. The willows are shaded out by the poplars and a new vegetation understory develops with rose (*Rosa acicularis*), highbush cranberry (*Viburnum edule*) and horsetail (*Equisetum* sp.). Freezing and thawing are slower at this stage and there is less temperature fluctuation because of the insulating effect of leaf litter. There is also slower heat conductivity of the silty loam which also provides more nutrients and retains moisture, now no longer a limiting factor.

The subsequent white spruce and black spruce succession stages are accompanied by development of thick moss and organic layers. Soil temperatures become cooler throughout the summer. As thawing becomes slower, a permafrost layer develops; this prevents drainage and creates a wetter soil. Tree growth is then slower, either because of the wet soil or colder temperatures. As succession continues, the permafrost layer is closer to the surface and nutrients are depleted so that phosphorus, nitrogen and manganese may be limiting.

Thus, succession proceeds from the almost xeric conditions of the gravel bar to the mesic conditions of balsam poplar and white spruce and

Continued ...

Viereck, L.A. 1970. Continued

eventually to the hydric condition of the slow-growing black spruce. In the latter stage, with its thick sphagnum moss mat, the permafrost table is approximately 20 to 30 cm below the moss surface.

The river gravel has a pH of 5.0 to 5.6 but with river silt deposits it becomes more acidic (4.5 to 5.0). With changing litter from deciduous to coniferous and development of a moss layer, older spruce stands eventually grow on soils with a pH of 3.6 to 3.7.

1. VIVYURKA, A.J.
2. 1975
3. Rehabilitation of uranium mines tailings areas.
4. Canadian Mining Journal 95:44-45
5. Original
6. a. Ontario; Canadian Taiga

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. Treatment of seven tailings from uranium mines near Elliot Lake, Ontario consisted of added agricultural limestone in quantities up to 30 tons/acre. The pH of tailings was not raised to the neutral point but no problem occurred in growing grasses in acidic areas. Ammonium and sodium were also tried as neutralizing agents; they worked quickly but large amounts were required and they leached out quickly because of high solubility. Experience showed that mixing and cultivation of limestone with the tailings enhanced neutralization, but caused a dust problem because the tailings dried out as a result of manipulation. The author also found that small amounts of standard fertilizer added often were better than a single larger application once or twice per year.

At this location, August proved to be the best planting time to allow plants to establish before winter. In springtime, the tailings were too wet. Climax timothy, Kentucky bluegrass and birdsfoot trefoil gave satisfactory growth with best results in low areas where moisture gathered and poorest germination on drier, higher areas.

A 1 to 2 inch mulch layer of bark fines encouraged good germination and growth. Irrigation was tried and gave slightly better growth but not enough to justify the cost involved. A surface impermeable layer was also costly, at $4,000/acre, and therefore recommended only for extreme problem areas.

Besides revegetation, other stabilization methods involving limestone, lime slurry, fine sawdust, and waste soil material were considered. The author suggested that the ultimate program will probably include a top-coating technique for waste materials plus vegetation as a permanent covering.

1. VOGEL, W.G.

2. 1973

3. The effect of herbaceous vegetation on survival and growth of trees planted on coal-mine spoils.

4. In: National Coal Association, Research and Applied Technology Symposium on Mined-Land Reclamation, Pittsburgh, Pennsylvania, p. 82-92

5. Original

6. a. Kentucky; Eastern Forest

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. Experimental plantings conducted in southeastern Kentucky indicated that establishing both trees and herbaceous vegetation at the same time is desirable for the reclamation of strip-mined spoil banks, where both are desired. Herbaceous species compete to some degree with trees but the competition can be lessened by encouraging legumes and by avoiding strongly competitive grasses. In contrast, trees planted into an established stand of herbaceous vegetation have less chance of survival.

Four species of trees (cottonwood, sycamore, Virginia pine and loblolly pine) were planted in the following arrangements: (1) a control with no herbaceous cover; (2) trees with no herbaceous cover but fertilized with N and P; (3) trees fertilized with N and P and sown to weeping lovegrass (*Eragrostis curvula*) at 4 lb/acre and Kentucky-31 tall fescue (*Festuca arundinacea*) at 16 lb/acre; and (4) trees planted and fertilized with N and P and sown to grass and legumes (*Lespedeza cuneata* and *Lespedeza stipulacea*). The spoils were located at two sites, one predominantly composed of grey shale with a pH range of 6.0 to 8.0, and the second composed of sandstone and shale with pH ranging from 5.0 to 6.0.

Results at the end of the first growing season showed that the percentage of ground surface covered by vegetation averaged 65% for the grass-only plots and 70% for the grass-plus-legume plots. At the end of the third growing season, coverage in both categories had increased to 95% and some vegetation had encroached on the unseeded plots. By this time, the *Lespedeza* had become dominant in the grass-plus-legumes plots with an average cover of 60% in all plots in this category. By the end of the fifth growing season, the legumes comprised nearly all the vegetation cover in the grass-plus-legume plots.

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Vogel, W.G. 1973. Continued

Survival of trees was not significantly reduced by a herbaceous cover, but tree height growth was significantly repressed during the first three years. Grass alone suppressed the growth of trees slightly more than the combination of grass plus legumes. In the fourth growing season for pines, their growth in the grass-plus-legumes plots was about equal to that in the no-cover plots.

In the fourth and fifth years, the growth of trees in the grass-plus-legume plots exceeded tree growth in the other plots, including those with little herbaceous competition. It is assumed that *Lespedeza* provided nitrogen to the trees. Nitrogen for trees was particularly deficient in the grass-only plots, and even after five years there was suppressed cottonwood and sycamore growth. The difference was less for the pine species.

Tree survival in the fourth and fifth years in the grass-plus-legume plots continued to decline, a fact explained by smothering of tree seedlings by the dense cover of *Lespedeza* when the latter died back in autumn. This could be corrected by the selection of a less competitive quick cover species.

The tall fescue proved more competitive than the other herbaceous species and crowded out the initial cover of weeping lovegrass. By the end of the third growing season, *Lespedeza* crowded out both grasses and became dominant, after which tree growth improved. A less competitive mixture may be the weeping lovegrass and *Lespedeza*, leaving out the tall fescue. However, Vogel and Berg (1975) found that warm-season species (weeping lovegrass and *Lespedeza*) restricted seeded black locust less than cool-season species (ryegrass and tall fescue).

Other methods of reducing the competition from herbaceous species to trees are: adjusting the proportions of different species in the seed mixture; and lowering the application of fertilizers, especially nitrogen, to reduce the competition from grass. Some tree species may be less affected by herbaceous competition than others, but this is a subject requiring research.

1. WALKER, D., R.S. SADASIVIAH and J. WEIJER

2. 1977

3. The utilization and genetic improvement of native Alberta grasses from the eastern slopes of the Rocky Mountains.

4. Department of Genetics, University of Alberta, Edmonton. Unpublished report. 52 p

5. Original

6. a. Alberta; Rocky Mountains

   b. Alpine, Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. This project sought to collect, increase and maintain a seed source of grasses native to the Rocky Mountain region of Alberta, and to select from this collection the most promising species for revegetation of disturbed areas and for wildlife range improvement, particularly winter range improvement for elk and bighorn sheep.

By applying the most advanced techniques of agricultural practice and plant genetics, it is hoped to provide a function similar to that of the Soil Conservation Service of the United States plant material centers.

Disturbed areas in the mountain regions are often too harsh an environment for commercially available grasses. Native grass species, which are adapted to the climatic and soil conditions through many thousands of years of selection, are a likely solution to this revegetation problem.

Selection of native species and strains of species was done according to the following criteria: (1) wide adaptability; (2) high yield of seed production; (3) high forage value; (4) low shattering (the ability of plants to retain their seeds until harvesting is complete); (5) large seed size; (6) disease-free varieties; and (7) selection of some species of low forage production for these circumstances where low fire hazard is the objective and where wildlife attraction is not desired.

Preliminary observations on transplant studies at mountain test sites indicated that plants from one geographical location of the Rocky Mountain region can grow in other locales. Transplanting container-grown native grass plants can be a very effective method of rapidly establishing a ground cover on drastically disturbed areas with extreme climatic conditions. The ease with which the transplanted grasses survived in this study indicated that lack of vegetation could be due to seedling

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Walker, D., R.S. Sadasiviah and J. Weijer. 1977. Continued

mortality and that seedling establishment is the greatest problem in the successful utilization of native species. Species used in the 1975 transplant studies were: *Agropyron dasystachyum, Deschampsia caespitosa, Festuca saximontana, Poa arctica, Poa alpina, Stipa columbiana* and *Trisetum spicatum*. Further 1976 transplants will be assessed.

Problems prohibiting the large scale agricultural production of native grass seed include: seed shattering, low yields, hairs and awns, intermittent flowering, low fertility and uneven ripening. Some of these problems can be solved through genetic improvement and some through agricultural engineering technology. Slender wheatgrass (*Agropyron trachycaulum*)and northern wheatgrass (*Agropyron dasystachyum*) are two outstanding native species which show the most potential for utilization.

Hybrids obtained by intercrossing selected genotypes from different geographical regions within species can be used to develop varieties of wide adaptability. Development of synthetic or multiline varieties is extremely important for revegetation purposes under diversified environmental conditions. However, development of such varieties requires from eight to ten years. Among the *Agropyron* species studied, *Agropyron dasystachyum, Agropyron trachycaulum, Agropyron latiglume* and *Agropyron subsecundum* are considered outstanding for the development of varieties.

Approximately one fifth of an acre was seeded to each of eight species of native grass seed collected from Ellerslie plots, near Edmonton, in 1975. The eight species were: *Agropyron dasystachyum* (Northern Wheatgrass); *Festuca idahoensis* (Idahoe Fescue); *Agropyron subsecundum* (Bearded Wheatgrass); *Agropyron trachycaulum* (Slender Wheatgrass); *Koeleria cristata* (Junegrass); *Phleum alpinum* (Alpine Timothy); *Trisetum spicatum* (Spike Trisetum); *Stipa columbiana* (Sub-alpine Needlegrass). These have germinated and are expected to yield seed in 1977.

The authors recommended that testing of selected genotypes of promising native species at mountain sites should be carried out and techniques for assisting native seed establishment such as mulches and seedbed preparation should be determined.

1. WEIN, R.W. and D.A. MacLEAN

2. 1973

3. Cotton grass (*Eriophorum vaginatum*) germination requirements and colonizing potential in the Arctic.

4. Canadian Journal of Botany 51:2509-2513

5. Original

6. a. Alaska, Yukon, Mackenzie District; Central Alaska Taiga, Alaskan Tundra, Canadian Tundra

   b. Yukon and Northwest Territories; Roads

7. Germination requirements of cotton grass (*Eriophorum vaginatum*) were determined using seed collected from Alaska (north of Fairbanks and at Prudhoe Bay), Yukon (Rat River) and the Northwest Territories (Tuktoyaktuk and burned and unburned areas near Inuvik).

Flowering is irregular from year to year and there is wide variation in seed production for this species. Maximum seed production was 15.7 kg/ha from a burned site at Inuvik (4 times the amount of an unburned site) and 8.6 kg/ha from an undisturbed site at Tuktoyaktuk.

Optimum germination temperatures were close to 30° C, with a minimum temperature close to 15° C and a critical maximum temperature of 35° C. The seed of cotton grass has no adaptive mechanism for survival against fire. Germination occurred at the optimum temperature over a 10-day period, with 90% germination occurring in a 3-day period.

Arctic cotton grass is apparently adapted to germinate only on the soil surface where temperatures are sufficiently high in summer, possibly as a protective mechanism against untimely germination during the brief arctic summer. Light treatment enhanced germination but was not an absolute requirement. Percentage germination did drop considerably without light, for example 42% in 11 days of dark incubation.

Cotton grass proved to be more drought tolerant than *Arctagrostis latifolia*, *Calamagrostis canadensis* and *Festuca brachyphylla* but less so than *Poa lanata*. These are all species that invade disturbed tundra sites and cotton grass germinated under less favourable moisture conditions than most.

No prolonged seed dormancy was evident and seed lost viability during storage. In one instance, loss was high over 10 months at room conditions; in another instance up to 52.5% of the seed remained viable at 19 months. Low-germination seed was collected in this study in

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Wein, R.W. and D.A. MacLean. 1973. Continued

August or early September while high-germination seed was collected within two weeks of initial seed dispersion. Seed should be gathered as soon as dispersion begins (in early July at Inuvik). Best yields are found on disturbed sites such as burns. Seed sown in July will germinate as under natural conditions but August-sown seed may not be sufficiently developed to overwinter. Seeds should be dry stored at below-freezing temperatures for storage until required.

Cotton grass has special value in disturbed areas where wet mineral soil is exposed, such as drainage ways or where the water table remains close to the soil surface. Because of its low seed yield per hectare, it should particularly be used on wet sites and secondarily for mesic sites. The soils of mesic sites become colder as organic matter accumulates over time and in these circumstances cotton grass can be a strong component as grasses and forbs show reduced vigour. Few other species can invade mineral soils which are supersaturated for much of the summer.

Cotton grass does not compete well with *Calamagrostis canadensis* in minor disturbed areas of little peat layer disruption which dry out in summer. In wet areas with peat substrate, *Arctagrostis latifolia* and *Senecio congestus* are successful pioneers. Where there is major disturbance with much exposed mineral soil, *Epilobium angustifolium* and *Calamagrostis canadensis* dominate early. These two species cannot germinate in droughty conditions but are more drought tolerant in the seedling stage than arctic cotton grass.

1. WESTON, S.
2. 1973
3. Report on developments and progress in reclaiming waste dumps and tailings ponds.
4. Western Miner 46(8):29-37
5. Original
6. a. Canada

   b. Yukon and Northwest Territories; Overburden, Roads, Tailings

7. Efforts to revegetate tailings ponds and waste areas have often resulted in failure because of some basic errors in the approach to vegetation establishment. Tailings and mine wastes have little similarity to agricultural soils. The latter, by definition, possess three characteristics: (1) a mineral mass, containing plant nutrients, derived from the breakdown of the original parent material; (2) organic matter, some of which is in the form of humus; and (3) the soil is alive with micro-organisms. Mine tailings lack these characteristics and present special problems. However, in the author's experience there appears not to be any phytotoxic properties associated with any tailings pond materials which cannot be corrected.

The author also indicates that reclamation is economically feasible. Timing is of major importance and use of aircraft for seeding and fertilizing is recommended whenever possible. This ensures that seeding can be done at the most desirable time. Access at the right time, poor seed distribution and cost are factors that make ground machinery less desirable. Aircraft are superior to either hydroseeders or hand seeders for better distribution of seed and fertilizers. Fall seeding, particularly for areas which experience drought conditions, permits the advantage of spring moisture for establishment.

Mulch, topsoil and mechanical or chemical stabilizers are not recommended. Mulches provide only temporary assistance and it is cheaper to apply a higher seed and fertilizer rate instead. Mulching is necessary only where adverse conditions prevail for a considerable period of time. Careful timing, aerial seeding and use of quick germinating species can minimize adverse conditions and the high cost of the former methods.

Replacement of topsoil is not necessarily the answer because roots may not penetrate beneath the soil into the tailings. In such cases, a shallow blanket may be created, and it would easily be eroded. Chemical

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Weston, S. 1973. Continued

stabilizing agents can be undesirable because inoculated leguminous seeds may not survive if mixed with chemical stabilizers.

Reports on reclamation projects in eastern Canada, reveal that an agricultural approach has been used to reclaim tailings ponds at considerable cost. A new approach is needed, using the tailings as they exist except for nutrient amendments. As an example of this suggested approach, the author planned reclamation of 312 acres for Placer Development Limited in British Columbia. The essential steps were site examination and physical and chemical tests of the tailings for nitrogen, phosphate, potash, calcium, magnesium, pH, electrolytic conductivity level, and tailings texture.

The absence of organic matter from tailings means that they have no buffering capacity to a change in pH. Small amounts of acid material will affect pH readings more than in normal soils where organic matter absorbs anions and cations.

Seed mixes should be designed for a specific area, using plants of diverse root systems for a maximum holding capacity of the soil. Annual ryegrass was used in this study as a nurse crop because it germinates quickly giving quick surface control. It also allowed slower germinating species to become established. The mix consisted of boreal fescue, crested wheatgrass, pubescent wheatgrass, streambank wheatgrass, slender wheatgrass, white dutch clover, and alfalfa. An important feature of this type of seed mix is that the alfalfa and clover have a high percentage of hard seed which may not germinate for many months after seeding as a safeguard agains adverse conditions at seeding time.

Until the soil-building characteristics of the grasses and legumes have been able to create more amenable soil conditions, tree planting should be deferred. Fertilizers should be added to tailings as and when required and to the extent it is economically feasible, at least for the initial two or three years. Fertilizer is of no use when the root systems are not developed. The cost of fertilizer application by aircraft or hand operated seeder is very similar so that the site location can determine the method.

Chemcial reagents used in the ore processing may have to be leached from tailings before seeding commences. Flushing with fresh water is recommended to remove any residual chemicals not recycled at the mill.

Revegetation costs vary according to site location, the type of seeds and fertilizer used, whether a surface crust on the tailings requires ripping before seeding or other ground preparation, if an irrigation system is applied temporarily, and the cost of maintenance fertilization. For this study area, it was expected that five fertilizer applications of 200 lb/acre would be required.

From the author's experience with nutrient sterile-soils in eastern and western Canada, it is suggested that the soil-building process can take place rapidly, and tailing areas can be productive within three years from the start of reclamation.

1. WILLARD, B.E. and J.W. MARR

2. 1971

3. Recovery of alpine tundra under protection after damage by human activities in the Rocky Mountains of Colorado.

4. Biological Conservation 3:181-190

5. Original

6. a. Colorado; Rocky Mountains

   b. Alpine; Roads

7. This study describes the process and rates involved in the recovery of alpine tundra when protected after damage by visitors' trampling. Such trampling kills plants and initiates erosion processes which eventually remove all plants and finer organic and mineral particles.

It was found that by a system of exclosures, recovery of vegetation trampled for one year showed almost complete recovery if given a four-year recovery period. An area which had been trampled over a 26-year period had an increase in vegetative growth with *Kobresia myosuroides* as the dominant species. However, an area which had received trampling for 38 years showed no improvement during four years of exclosure.

Despite this relatively rapid recovery by certain plant species, the authors suggest from this study and others that the time interval required for ecological processes to produce a natural and persistent (climax) ecosystem would be several hundred to a thousand years in some areas of trampling.

1. WILSON, H.A.
2. 1957
3. Effect of vegetation upon aggregation in strip mine spoils.
4. Soil Science Society of America Proceedings 21:637-640
5. Original
6. a. West Virginia; Eastern Forest

   b. Southwestern Mackenzie, Southern Yukon; Overburden

7. This study in northern West Virginia sought to determine if aggregates were present in 10-year old coal spoil, with and without vegetation, and to compare the degree of aggregation with that in adjacent unstripped soil and in two 100-yr-old iron ore spoils that were covered by trees and herbaceous plants.

The results showed that the vegetated portion was better aggregated than the non-vegetated portion. However, aggregation in the vegetated portion of coal mine spoil was poorer than in the undisturbed soil.

The type of vegetation which is established on the spoil exerts as much effect upon spoil aggregation as it does on soil aggregation. A good cover of forage grasses and legumes has a more stimulating effect upon aggregation than a cover of black locust, for example, and the latter is more effective than a cover of pine. However, 10 years is too short a time for spoil with a grass or herbaceous cover to be as well aggregated as adjacent undisturbed soil. The century-old iron-ore spoils, with a cover of oak, yellow poplar and shrubs, were not as well aggregated as the adjacent unstripped soil.

1. **WISTRAND, G.**

2. 1976

3. Nya iakttagelser över gräsinsåningarna vid Silvervägen i Arjeplog. [The artificially sown roadbanks along the Graddis Road, N. Sweden].

4. Svensk Botaniska Tidskrift 70:155-163

5. Author's abstract

6. a. Sweden; Fennoscandian Highlands

   b. Alpine, Southwestern Mackenzie, Southern Yukon; Roads

7. This paper reports the development of the grass cover of roadbanks along the Graddis road (constructed 1964-1974) which passes through the high-mountain area of Arjeplog (Pite lappmark, N Sweden). The banks have been sown with mixed grass seed. Observations show that *Festuca rubra* is becoming increasingly dominant, but the tendency is less marked on moist or clayey ground. The apophytic flora of the roadbanks is relatively species-poor and the number of individuals is low except in some places where the surrounding birchwoods are especially rich in herbs. Weeds that were introduced with the grass seed are on the whole not native to the area and often disappear after one or a very few years. An exception is *Trifolium hybridum* which often survives and can give rise to extensive stands. Scattered individuals of some other species are able to survive for several years. Weeds originating from ruderal habitats (settlements, etc.) within the area show a stronger tendency to establish themselves in the sward and may even spread to the natural vegetation adjoining the road.

1. YOUNKIN, W.E.

2. 1972

3. Revegetation studies of disturbances in the Mackenzie Delta region.

4. In: L.C. Bliss and R.W. Wein, Editors, Botanical Studies of Natural and Man-Modified Habitats in the Eastern Mackenzie Delta Region and the Arctic Islands, Arctic Land Use Research Programme, Indian and Northern Affairs, Ottawa. ALUR 71-72-14, p 175-228

5. Original

6. a. Mackenzie District; Canadian Tundra

   b. Mackenzie Delta Region, Yukon Coast; Roads

7. This report examines the possibility of using agronomic species for re-seeding disturbed areas. Planting trials were conducted at Inuvik, Tununuk Point and Tuktoyaktuk in 1970 and 1971. Based on these studies, the following conclusions and recommendations are made.

The best time of planting is early spring prior to complete snowmelt because there is enough moisture to promote good germination and seedling establishment. Fall seeding just before or after first snowfall is also possible, in which case the seed would lie dormant until spring snowmelt. An increasingly cooler soil microenvironment further north, particularly for organic soils, means that productivity is less and seedling establishment more tenuous. As a result, seeding should be progressively later at increasing latitudes.

In the fertilizer trials, it was found that a combination of 100 kg/ha elemental nitrogen and 200 kg/ha of elemental phosphorus provided the most productive fertilizer for both organic and mineral soil. One hundred kg/ha elemental phosphorus alone was best for organic soils. On a cost benefit basis, a nitrogen:phosphorus ratio of 1:1 is probably the best fertilizer treatment with nearly similar results to that achieved from a nitrogen:phosphorus ratio of 1:2.

Seed head production was increased by the application of phosphorus alone or in combination with nitrogen or lime, and was particularly evident for meadow foxtail, slender wheatgrass, Canada bluegrass, Kentucky bluegrass and timothy. If such seed is viable, the application of phosphorus is a means of enhancing self-maintenance of these introduced species.

Species that provided the greatest productivity were timothy, meadow foxtail and slender wheatgrass. Species providing the greatest ground

Continued ...

Younkin, W.E. 1972. Continued

cover were red fescue, Kentucky bluegrass and Canada bluegrass. The latter species provided little cover in the first year, but by the second year cover was dense.

Species mixes were recommended because a combination of species widens the range of microenvironments that will support successful seeds. An appropriate mix combines fast growing but less hardy species, along with a slower growing hardy species. Reed canarygrass and orchardgrass provide good nurse crops when mixed with various hardy grass species.

Older seismic lines in the study area were being revegetated by two native grass species, *Arctagrostis latifolia* and *Calamagrostis canadensis*. These grasses are not dominant in undisturbed communities but quickly become dominant in disturbed areas, even from a small seed source.

1. YOUNKIN, W.E.

2. 1973

3. Autecological studies of native species potentially useful for revegetation, Tuktoyaktuk region, N.W.T.

4. In: L.C. Bliss, Editor, Botanical Studies of Natural and Man-Modified Habitats in the Mackenzie Valley, Eastern Mackenzie Delta Region and the Arctic Islands, Arctic Land Use Research Program, Indian and Northern Affairs, ALUR 72-73-14 and Environmental-Social Committee Northern Pipelines, Task Force on Northern Oil Development Report 73-44, p 45-76

5. Original

6. a. Mackenzie District; Canadian Tundra

   b. Mackenzie Delta Region, Yukon Coast; Roads

7. This study assessed the revegetation potential of selected native species, especially *Calamagrostis canadensis* and *Arctagrostis latifolia* which were observed to naturally reseed disturbed areas. The study also characterized the differences in microenvironment between disturbed and adjacent undisturbed tundra in the Tuktoyaktuk region.

From the study some tentative conclusions were made:

1. The two important colonizing species, *Arctagrostis latifolia* and *Calamagrostis canadensis*, are unimportant in the undisturbed tundra but provide a relatively large and viable seed source which has the ability to germinate under a range of moisture and temperature conditions.

2. The important native species tested, *Betula nana, Eriophorum vaginatum,* and *Carex bigelowii*, though providing large seed sources, were either low in viability or did not germinate easily.

3. *Arctagrostis latifolia* establishes slowly the first year but overwinters well, growing rapidly the second year, sending out creeping rhizomes with as many as 5 to 7 shoots per plant.

4. Mature plants of both *Arctagrostis* and *Calamagrostis* send out creeping rhizomes which aid in the rapid colonization of disturbed areas.

5. *Arctagrostis* is better adapted to growing in cold nutrient rich soils than *Calamagrostis*, producing larger shoot systems, and root systems which are both larger and penetrate deeper into cold soils.

Continued ...

Younkin, W.E. 1973. Continued

6. The microenvironment in the 1965 seismic lines differs from that of the adjacent tundra in several ways:

a) snow accumulates more and remains longer in the seismic lines;

b) the surface of the seismic lines is 45 to 65 cm below the surface of the adjacent tundra;

c) soil temperatures in the top 10 cm of the seismic lines are 2 to 3° C warmer than in undisturbed hummocks and 4 to 8° C warmer than in hollows;

d) the active layer in the seismic lines is 10 to 20 cm greater than on undisturbed hummocks and 20 to 30 cm greater than on hollows;

e) the peat layer in the undisturbed tundra is more important in preventing permafrost meltout than the vegetation.

In undisturbed tundra, *Calamagrostis canadensis* has a wider ecological amplitude than *Arctagrostis latifolia*. It can survive on shallowly or deeply thawed soils and in moist to dry conditions. *Calamagrostis* is found on mineral or organic soils but most frequently on peaty soils. It is thought that its lack of vigour on undisturbed tundra indicates it is near its limit of tolerance so that its continued existence may be dependent on tundra disturbances. *Arctagrostis latifolia*, although circumpolar, has a narrower range of tolerance and is restricted to above 55° N latitude. It achieves importance in mesic to moist environments where the active layer is greater than 35 cm. It is the more highly adapted of the two to arctic environments.

Other less important colonizing species such as *Epilobium angustifolium* and *Senecio congestus* are rarely found in undisturbed tundra communities. Species important in undisturbed areas, such as *Betula nana*, *Carex bigelowii* and *Eriophorum vaginatum* produce large amounts of seed but these are either non-viable or difficult to germinate.

The inclusion of *Arctagrostis* and *Calamagrostis* in revegetation programs seems appropriate as these species possess a genetic potential for growth under normal arctic conditions but they are also highly enough adapted to withstand extremes of conditions which might eliminate other species.

Research needs related to these two grass species are: 1) to determine if they can be raised in lower latitudes where farm land and machinery are available for larger seed production; and 2) seed collections should be made at various latitudes along the proposed pipeline route to identify and test ecotypes for a revegetation program.

1. YOUNKIN, W.E.

2. 1974

3. Ecological studies of *Arctagrostis latifolia* (R. Br.) Griseb. and *Calamagrostis canadensis* (Michx.) Bauv. in relation to their colonization potential in disturbed areas, Tuktoyaktuk Peninsula region, N.W.T.

4. University of Alberta, Edmonton. Ph.D. Thesis. 148 p

5. Original

6. a. Mackenzie District; Canadian Tundra

   b. Mackenzie Delta Region, Yukon Coast; Roads

7. *Arctagrostis latifolia* and *Calamagrostis canadensis* were studied to identify factors that influence their distribution and importance in disturbed and undisturbed tundra plant communities on the Tuktoyaktuk Peninsula.

Arctagrostis has a circumpolar distribution and a north-south range between 55 and 85°N. *Calamagrostis* is an arctic-boreal species limited to the North American continent, with a north-south range between 35 and 70°. The latter has over 100 species in the genus, while there are only three distinct species of *Arctagrostis*.

In undisturbed habitats, *Calamagrostis* ranges from imperfectly drained areas to those that are moderately well-drained. It occurs primarily as weak clumps of chlorotic leaves with few flowering stalks. *Arctagrostis* is found in few undisturbed habitats but occurs in imperfectly drained soils and where the active layer is greater than 35 cm. Both are minor components of undisturbed areas, constituting about 1% of total cover in such areas.

Both grasses are important colonizers of all but the wettest disturbed habitats. Their cover in disturbed areas increases 30 to 80 times over that in undisturbed habitats. Other species that are important in undisturbed habitats (*Betula nana* ssp. *exilis*, *Salix glauca*, *Eriophorum vaginatum*, *Vaccinium vitis-idaea* and *Lupinus arcticus*) invade disturbed sites much more slowly and seldom produce the same degree of cover as that produced by these two grasses. The net annual ground production of the two grasses in a disturbed area was measured as 280 g/m^2, five times that of adjacent undisturbed tundra.

The nutrient status of disturbed soils was found to be little different from that in undisturbed soils. The latter have a high organic content while disturbed soils are primarily mineral. Disturbance removes the

Continued ...

Younkin, W.E. 1974. Continued

nutrient-rich organic mat but its removal is compensated for by large increases in the active layer which increases the available nutrient reservoir. Soil temperature and active layer thickness increase significantly with disturbance. Plants growing in disturbed areas have significantly higher tissue concentrations of nitrogen and phosphorus and have somewhat less tissue water stress.

Arctagrostis develops earlier than *Calamagrostis*, with seed set by mid-August when *Calamagrostis* is just beginning anthesis. *Arctagrostis* is the larger and more vigorous of the two species and produces two to three times the number of flowering heads, and 50 to 150 times more seed. Seeds of these two colonizing species are more viable and more easily germinated than non-colonizing species. However, they constitute a much lower total seed source because of their relatively low abundance in undisturbed habitats. *Arctagrostis* germination is significantly affected by disturbance and slope position; speed and completeness of germination are greater from collections on disturbed areas than on undisturbed areas, and greater on mid-slope and hilltop areas than in depressions.

On cold, low nutrient soils, *Arctagrostis* produces nearly twice the root system of *Calamagrostis*. In growth chamber tests, *Arctagrostis* root systems responded more positively to nutrient additions at low temperature than did the roots of *Calamagrostis*. In nutrient accumulation comparisons, *Calamagrostis* had the greatest accumulation per unit of root biomass for nitrogen and phosphorus while *Arctagrostis* was more efficient in potassium accumulation. Low nutrient availability is one of the major factors limiting growth of these grasses in undisturbed tundra. Neither species seems well adapted to compete for nutrients in the upper, warmer soil horizon where most roots are concentrated. They depend on areas of deep soils and a root tolerance to low soil temperatures for nutrient extraction. *Arctagrostis*, more cold tolerant but possessing a less efficient root system, is more restricted in distribution to areas of deeper thaw. *Calamagrostis*, with the more efficient nutrient accumulation capability of the two, can compete in shallow soils and this increases the number of habitats available for this species.

In summary, disturbance in a closed tundra community results in soil warming, increase in soil volume and increase in nutrient pool, with the result that such areas are invaded by small, mobile and highly viable seeds of these grasses. Vigorous seed production, rapid growth and rhizomatous spreading result in relatively rapid colonization. The rapid biomass production eventually insulates the soils to allow the permafrost table to rise, and the disturbed area then becomes a habitat for forbs, deciduous shrubs and evergreen shrubs.

1. YOUNKIN, W.E.

2. 1976

3. Introduction

4. In: W.E. Younkin, Editor, Revegetation studies in the northern Mackenzie Valley region, Prepared by Northern Engineering Services Company Limited for Canadian Arctic Gas Study Limited, Biological Report Series, Volume thirty-eight. Chapter I, 6 p

5. Original

6. a. Mackenzie District; Canadian Taiga, Canadian Tundra

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Mainland Tundra, Yukon Coast, Northern Yukon, Southern Yukon; Roads

7. Early revegetation studies that were started by Northern Engineering Services Company Limited in 1971 emphasized the use of revegetation to retard thermal erosion or reduce the visual impact of scars created by oil exploration or delivery systems. Consequently, most of the research was directed toward selecting species and fertilizer combinations to provide a relatively rapid and long lasting cover of agronomic grasses. However, this research revealed that revegetation alone could not prevent or significantly retard thermal erosion after the destruction of the natural insulative mat, and also that the establishment of a dense cover of agronomic grasses on disturbed areas could inhibit the re-establishment of the better adapted and more ecologically desirable native vegetation. Current revegetation objectives are directed to obtaining an understanding of the natural recovery process. The broad revegetation objectives now are to identify and evaluate means of: (1) stabilizing disturbed areas to prevent alluvial erosion; and (2) aiding in the recovery of disturbed areas to stable, self-maintaining states.

In the permafrost region, two main forms of erosion occur: (1) thermal erosion, where ground ice melt out leads to slumping and slope failure and (2) alluvial erosion, where soil is removed by the surface flow of water. Because the harsh arctic environment prevents the rapid establishment of a vegetative cover, neither type of erosion can be prevented by revegetation efforts alone. Most of the thermal erosion and, on steeper slopes, some alluvial erosion will occur in the first year following disturbance before a protective plant cover can be established. Therefore, adequate erosion protection, especially during the first years will require an integration of both biological and engineering erosion control measures. Engineering measures are needed to provide the initial surface and subsurface stabilization while a plant cover is being established. In time the plant cover is expected to reduce and in many areas replace the need for mechanical erosion control devices.

Continued ...

Younkin, W.E. 1976. Continued

In areas of low erodibility, the primary revegetation objective is that of encouraging natural recovery. This requires information on (1) rates and processes of natural recovery and (2) methods of modifying disturbed areas to speed the natural recovery process. Studies of two native grasses (*Arctagrostis latifolia* and *Calamagrostis canadensis*) have shown that although they provide little cover in many undisturbed plant communities, they are among the first to invade and colonize disturbed areas. These colonizing species are well adapted to the northern environment and appear to be logical inclusions in any seeding program aimed at both long-term vegetation establishment and at aiding the natural recovery process. In 1973, Northern Engineering Services Company Limited began studies of these two species in anticipation of eventually including them in a seed increase program.

1. YOUNKIN, W.E.

2. 1976

3. Preliminary pipeline revegetation specifications for the Mackenzie Valley region, N.W.T.

4. In: W.E. Younkin, Editor, Revegetation studies in the northern Mackenzie Valley region, Prepared by Northern Engineering Services Company Limited for Canadian Arctic Gas Study Limited, Biological Report Series, Volume thirty-eight. Chapter IV. 23 p

5. Original

6. a. Mackenzie District; Canadian Taiga, Canadian Tundra

   b. Southwestern Mackenzie, Central Mackenzie, Mackenzie Delta Region, Mainland Tundra, Yukon Coast, Northern Yukon, Southern Yukon; Roads

7. The specifications outlined in this report are preliminary only and will be refined as more information becomes available. This report is a review of the information currently available on species and fertilizer trials conducted on the Arctic Coastal Plain and along the Mackenzie River Valley. Although a great deal of research has been done by various investigators, caution should be exercised in making direct comparisons of data as they have been gathered over different time spans and using different methods. In addition, it should be emphasized that none of these studies have been under way for more than six years, requiring that caution be used in predicting the long-term success of any revegetation programs.

In areas where erosion is not a problem, the main objective is to aid the re-establishment of the native plant communities. In these areas, high seed and fertilizer application rates may serve only to retard natural recovery; therefore, applications will be minimal and used to encourage natural revegetation rather than substitute for it.

From a thorough review of revegetation results by ARCO Chemical Company and Mitchell on the Alaska coastal plain and by Dabbs, Hernandez, Younkin and their co-workers in the Mackenzie District and northern Yukon, the author selected 12 species and varieties that show a potential for use along various sections of the proposed pipeline route. These are redtop (Reton, Smaragd), colonial bentgrass (Astoria), meadow foxtail (common), reed canarygrass (Frontier), timothy (Engmo), creeping red fescue (Arctared, Boreal), sheep fescue (Durar), Kentucky bluegrass (Nugget), Canada bluegrass (Cannon) and Upland bluegrass (Draylar). Where a cultivar was not listed for a given species, the results of species trials at Beaverlodge, Alberta, were used as a guide in selecting the most hardy. All of these species are recommended for use in soil conservation by the United States Department of Agriculture.

Continued ...

Younkin, W.E. 1976. Continued

In relation to native species, studies by Mitchell over a 3-year period in the Prudhoe Bay area have shown that *Puccinellia* spp., *Arctagrostis latifolia, Calamagrostis canadensis, Deschampsia* spp., and *Poa glauca* are some of the hardiest and best cover producers. The only agronomic species which performed as well was Arctared creeping red fescue, itself a native variety which is commercially available. In the Inuvik-Tuktoyaktuk region of the Northwest Territories studies have shown that the two native grasses *Arctagrostis latifolia* and *Calamagrostis canadensis* are winter-hardy and highly productive. Although work is underway on behalf of Canadian Arctic Gas Study Limited, Alaskan Arctic Gas Study Company, and the Department of Indian and Northern Affairs to increase the seed of these two grasses, many problems related to dormancy and flowering mechanisms still need to be solved before seed will be available for use in commercial quantities. The development of a native seed supply is considered an important part of the revegetation program in the Arctic; however, until successful seed production has been achieved, none of these species will be included in the seed specifications.

As a result of various seed mix studies and fertilizer trials in Alaska and Canada, which the author reviews in detail in this report, preliminary revegetation measures were recommended for the proposed pipeline route through the Low Arctic Tundra, Forest Tundra and Boreal Forest climatic regions. These specifications are summarized in the table on the next page.

Continued ...

Younkin. W.E. 1976. Continued

	Seed Specifications			
	Initial Seeding		Follow-up Seeding	
	species	rate (kg/ha)	species	rate (kg/ha)
A. LOW ARCTIC TUNDRA:				
High erodibility	NKB[1]	14	NKB	9
	ACRF	36	ACRF	19
	ET	6		
Medium erodibility	ACRF	40	ACRF	19
	ET	6	NKB	9
	MF	6		
	RT	6		
Low erodibility	ET	12	None planned	
	MF	6		
	ACRF	10		
B. FOREST TUNDRA:				
High erodibility	NKB	22	NKB	9
	ACRF	22	ACRF	19
	MF	11		
Medium erodibility	ET	11	NKB	9
	MF	11	ACRF	19
	BCRF	34		
Low erodibility	BCRF	11	None planned	
	MF	17		
C. BOREAL FOREST:				
High erodibility	BCRF	22	BCRF	17
	FRC	17	FRC	11
	SF	17		
Medium erodibility	BCRF	22	BCRF	17
	FRC	11	FRC	11
	MF	11		
	CB	11		
Low erodibility	BCRF	6	None planned	
	MF	11		
	FRC	11		

[1] NKB - Nugget Kentucky bluegrass
ACRF - Arctared creeping red fescue
ET - Engmo timothy
MF - Meadow foxtail
RT - Redtop
SF - Sheep fescue
BCRF - Boreal creeping red fescue
CB - Creeping bentgrass
FRC - Frontier feed canarygrass

Continued ...

Younkin. W.E. 1976. Continued

These revegetation specifications contemplate the need for sod replacement in the medium and low erodibility classes of the Low Arctic Tundra. Erosion control mats and stem cuttings are specified for the high erodibility classes in each of the three climatic regions.

The proposed mixes are generally a combination of slower establishing winter-hardy species with faster establishing less winter-hardy species in an attempt to optimize both immediate erosion protection and longevity. In areas of high erosion potential seed mixes consist of species capable of providing long-term protection. In areas of medium erodibility, a combination of species will be sown with emphasis on rapid establishment. Areas of low erodibility will receive a seeding of rapid establishing short-lived species.

A fertilizer mix containing N, P_2O and K_2O applied at 56, 112 and 56 kg/ha is specified for all disturbed areas of high or moderate erodibility. Areas of low erodibility and areas where a follow-up seeding is required will receive this same mix at one-half the rate. A basic premise for determining fertilizer use is that minimum quantities to achieve the necessary growth of grasses will be specified, avoiding unnecessary addition of nutrients into naturally low nutrient ecosystems.

The author recommended that the initial seed and fertilizer application be in the winter immediately after clean-up operations along the pipeline route. A ground-based winter seeding would ensure a uniform seed and fertilizer application. Winter seeding would also take advantage of the numerous micro-habitats formed by the frozen backfill and of the moisture provided by early spring snow melt.

1. YOUNKIN, W.E. and W. FRIESEN

2. 1976

3. Sans Sault revegetation trials.

4. In: W.E. Younkin, Editor, Revegetation studies in the northern Mackenzie Valley region. Prepared by Northern Engineering Services Company Limited for Canadian Arctic Gas Study Limited. Biological Report Series, Volume thirty-eight. Chapter II. 28 p

5. Original

6. a. Mackenzie District; Canadian Taiga

   b. Southwestern Mackenzie, Central Mackenzie, Southern Yukon, Northern Yukon; Roads

7. The Sans Sault test site is located at 65 40 N, 128 49 W and has been the locale for revegetation trials since 1971. This report summarizes measurements to 1975 which monitored the success of: (1) seeded agronomic species; (2) reinvasion by native species onto the backfill mound and exposed mineral soil; and (3) four agronomic species seeded onto sandy soils.

Of the 18 grasses seeded in 1971, meadow foxtail and reed canarygrass were the fastest establishing species, both providing an average cover of 63% in the first year. The living cover of all tested species declined over the 5-year test period. Creeping red fescue and sheep fescue maintained their cover best, but both of these suffered significant cover reductions in their fifth year. By the fifth year, stands of meadow foxtail had produced the greatest amount of litter, followed by fowl bluegrass and creeping red fescue.

The success of native species reinvasion appeared to be inversely dependent on the amount of cover provided by seeded species. For example, in 1975 the total cover of seeded grasses ranged from 85.4% for meadow foxtail to 2.3% for crested wheatgrass. Under these seeded grasses, the native plant cover was 24% and 99%, respectively.

On sandy soils, the two most successful species in 1975 were Kentucky bluegrass and creeping red fescue.

Shrub cuttings planted in September 1971 and June 1972 were checked for survival in August 1973 and 1974. Willows (*Salix alaxensis* and *Salix arbusculoides*)were more successful than alders. Willows generally had 90 to 100% survival over 2 or 3 winters; *Alnus crispa* died out completely the first winter and *Alnus incana* had a survival rate of only 60%.

Continued ...

Younkin, W.E. and W. Friesen. 1976. Continued

Cuttings planted in September (hardwood cuttings) had a somewhat better survival rate than those planted in June (softwood cuttings). At the time that this report was prepared, greenhouse trials were underway to test the response of 11 northern shrub species to various moisture regimes and hormone treatments. Field trials at northern locations were planned for the summer of 1976.

Three factors were considered when ranking species according to their potential ability to retard erosion: (1) first year cover - where erosion is a potentially serious problem the speed with which ground cover can be established will be important; (2) percent living cover by year five - this is an indicator of the proportion of the stand which is still productive and suggests something of the potential longevity of the species; and (3) percent total cover by year five - this combines both living and dead cover to provide an indicator of the potential erosion protection provided by the species. From the five year study conducted at the Test Site it would appear that in the boreal forest region, meadow foxtail, fowl bluegrass, reed canarygrass and creeping red fescue provide the best combination of the above three factors.

Species such as colonial bentgrass, tall fescue, redtop and rough bluegrass provide 30% to 50% cover the first year and then begin to die out providing room for reinvasion. These species provide an initial cover capable of reducing erosion but die back quickly enough that by year five a native cover of from 40% to 65% can be established.

Most of these suggested grasses are meadow species that do well in moist to wet environments which are common along the proposed pipeline route. Creeping red fescue and Kentucky bluegrass may prove to be useful in seed mixes designed for mesic or dry sites.

In a winter road study the rate of fertilizer application had a significant effect on first year cover production, but this effect was reduced the second year and absent by the third year. This suggests that, although helpful in promoting rapid cover, initial high fertilizer rates are of little value over the long term. The authors concluded that if a heavy plant cover is required to maintain the integrity of a right-of-way, refertilization will be necessary, with the most suitable fertilizer being one high in nitrogen. In areas where a heavy plant cover does not need to be maintained (areas of low erodibility) the use of heavy seed and fertilizer applications is questionable. The authors indicated that more information is needed on the minimum amounts of seed and fertilizer needed to encourage natural reinvasion of disturbed areas.

1. YOUNKIN, W.E. and H.E. MARTENS

2. 1976

3. Progress report on rig site seeding tests in the Mackenzie Delta region, N.W.T.

4. In: W.E. Younkin, Editor, Revegetation studies in the northern Mackenzie Valley region, Prepared by Northern Engineering Services Company Limited for Canadian Arctic Gas Study Limited, Biological Report Series, Volume thiry-eight. Chapter III. 65 p

5. Original

6. a. Mackenzie District; Canadian Tundra

   b. Yukon Coast, Mackenzie Delta Region, Mainland Tundra; Roads

7. The program described in this report began in 1973 as a limited study of the logistic and operational problems associated with aerial seeding in remote northern locations. The seed mixes selected for the earliest revegetation studies in the Mackenzie Valley were a combination of both slower establishing winter-hardy varieties and rapidly establishing less hardy varieties of grasses selected from species trials conducted in the region. From these studies it became evident that additional seed mixtures would be required to meet a variety of environmental conditions and the program was gradually expanded to include the testing of a number of species and seed mixes. Twenty-two rig sites and roads with a total area of about 55 hectares were seeded in 1973, 1974 and 1975 in the Mackenzie Delta region. Aerial seeding trials were done with a "Sling King" seed and fertilizer spreader, flown at 15 m above ground level. Most of the seeded sites were on the Mackenzie Delta and two were on the Peel Plateau.

The authors concluded that revegetation of these disturbed areas is possible, but success is dependent on several factors. Below normal growing season temperatures can greatly reduce seedling establishment. Vegetative cover within a region is also strongly influenced by soil texture with fine soil texture producing the greatest cover and course texture the least.

The application of a 2:2:2:1:1 seed mix (consisting of Boreal creeping red fescue, Nugget Kentucky bluegrass, Climax timothy, Frontier reed canary grass and Prolific spring rye, by weight) to rig sites in the Mackenzie Delta region demonstrated that:

1) Climax timothy, reed canary grass and Prolific spring rye can establish rapidly and provide a first year cover of up to 40%.

Continued ...

Younkin, W.E. and H.E. Martens. 1976. Continued

2) The above species are not winter hardy in this region but can supply a litter cover of up to 20% in the second year.
3) Seeded cover is greatly reduced in the second year.
4) When Nugget Kentucky bluegrass and Boreal creeping red fescue are included in this mix, they are slower to establish than the other species in the mix, and only become well established in the third year.

The 2:2:2:1:1 mix may be acceptable in more southern areas. When used on the Peel Plateau above the Trail River, this mix provided a cover of 18% in 1974 and 23% in 1975. Most of the initial cover provided by this mix was provided by timothy which provides rapid erosion control and a heavy litter layer the following year. Timothy is not extremely winter hardy but survival improves southward from the Mackenzie Delta.

Seeding rates of 28 to 56 kg/ha of the 2:2:2:1:1 seed mix or of Engmo timothy provided nearly as much cover as 112 kg/ha.

The selection of a seed mix for a site will depend upon the particular requirements of that site. For example:

a) If a site requires a rapidly establishing cover and a high litter cover (for erosion control) a seed mix high in Engmo timothy should be applied.
b) Where a slower establishing longer-lived cover is adequate, Nugget Kentucky bluegrass or Arctared creeping red fescue sown separately or in combination is best.
c) If, however, both a rapidly establishing and longer-lasting cover are required, a mix of Nugget Kentucky bluegrass and Arctared creeping red fescue with 1/5 proportion of timothy would appear to be best in the Mackenzie Delta region. In the Boreal forest where less winter kill of Engmo timothy occurs, the proportion of timothy in the mix can be increased without reducing the second year living cover.
d) Where native species invasion is to be encouraged, less winter hardy species such as timothy, applied at light seeding rates, would appear to be best.

On very coarse (gravel) soils, seed treatments alone are not adequate to establish a plant cover. Treatments such as gouging or roughening of the surface to create microsites to aid seedling establishment may be required.

Fertilizer was applied in late May and early June using a Bell 206 helicopter and "Sling King" seed bucket with a 1:2:1 mix of N, P, and K applied at 440 kg/ha (400 lb/acre). Refertilization one to two years after the initial fertilizer application produced increases in seeded cover ranging from 4 to 66% and increases in biomass production averaging 22%. Seed and fertilizer applications appear to have a positive effect

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Younkin, W.E. and H.E. Martens. 1976. Continued

on native plant invasion where the living cover of seeded vascular plants remains below 20%. As living cover of seeded vascular plants increases above 40% the cover of invading native species decreases. Dense stands of grass, as formed by Nugget Kentucky bluegrass and Arctared creeping red fescue, have a detrimental effect on native invasion.

This report contains details on the operation and calibration of the "Sling King" seed and fertilizer spreader in addition to the information summarized here.

1. ZASADA, J.C.

2. 1975

3. Revegetation in the arctic coastal plain - some considerations.

4. Unpublished report, part of the Environmental Impact Statement for the proposed arctic gas pipeline prepared for the U.S. Department of the Interior. 94 p

5. Author's summary

6. a. Alaska; Alaskan Tundra

   b. Yukon Coast, Mackenzie Delta Region, Mainland Tundra; Roads

7. An attempt has been made to summarize some of the available information on revegetation of plant communities following disturbance in the Arctic Coastal Plain. This report is not exhaustive for several reasons. First, time was not available to thoroughly search the literature for all pertinent information. Second, many reports were not available. Third and perhaps of greatest significance, is the fact that revegetation research in the Arctic Coastal Plain is a relatively new field of study and most studies have not been underway long enough for sufficient time to elapse. Thus many of the conclusions are tentative and much new information will be available in the next few years. The primary result is that revegetation programs must remain as flexible as possible in order to take advantage of new information and methods as they develop.

Artificial revegetative research has followed an agronomic approach almost exclusively, (i.e. use of artificial seeding and fertilization). Many species have been tested and the two best-adapted species for which seed is commercially available are Arctared fescue and Nugget bluegrass. Potentially, important native Alaskan tundra species have been identified and include tall arcticgrass, bluejoint, hairgrass and alkaligrass. Seed for these species is not available in large quantities; however seed increase programs have been initiated.

Fertilization is a requirement for rapid and successful establishment of grass cover and for maintenance of stands in subsequent years. Without additional applications of fertilizer (i.e. other than the initial application) it appears that the introduced grasses will lose their vigor and begin to drop out of the stand within 3 to 5 years. Native species should be fertilized for establishment but can maintain themselves at lower levels of fertility than the introduced species.

Continued ...

Zasada, J.C. 1975. Continued

Little information has developed on the rates of secondary succession following disturbance. Observations indicate that at least 15 to 25 years are required provided the soil is stable and erosion is absent or essentially so. More detailed information is required to fully understand the natural relationships involved in addition to those between the native and introduced species.

Further information is given on native species autecology as it relates to regeneration; methods of encouraging re-invasion of native species is an area where additional research appears to be needed.

1. ZASADA, J.C. and A.C. EPPS

2. 1976

3. Use of woody plant material in soil and site stabilization and rehabilitation.

4. In: M.N. Evans, Editor, Proceedings of the surface protection seminar, Theme: travel and transportation practices to prevent surface destruction in the northern environment, Bureau of Land Management, Anchorage, Alaska, p.284-295

5. Original

6. a. Alaska; South Coastal, Southern Alaska Taiga, Central Alaska Taiga, Alaskan Tundra

   b. Southwestern Mackenzie, Central Mackenzie, Southern Yukon, Northern Yukon; Overburden, Roads, Tailings

7. A greater variety of revegetation options are available if woody plants are used in addition to grasses. Although large-scale use of woody plants is presently hampered by a lack of adequate seed and transplant material, there is adequate knowledge available from the use of woody species elsewhere to apply these methods, with little modification, to northern revegetation sites.

The potential versatility available through use of woody plants is best illustrated by willow. Cuttings and seeding can be used. Planting of rooted seedlings from either natural sites or nurseries has been successful. Different willow species vary in their ability to produce roots on dormant, untreated cuttings. The experience to date indicates that *Salix alaxensis* roots more readily than either *Salix scouleriana* or *Salix bebbiana*. It is not known whether cuttings will stabilize very unstable areas as rapidly as grasses. Artifical seeding of willow needs to be tested on an operational scale. Recent research with Alaskan willows indicates that seed can be stored for periods of more than one year with little loss of viability. Willows are quite commonly regenerated by unrooted, dormant stem cuttings.

A recently established containerized seedling nursery at the Alaska Plant Materials Center, near Palmer, produces white spruce, Sitka spruce and cottonwood from Alaska, lodgepole pine from the Yukon, and Scots pine and Siberian larch from Finland.

Another recommended way to obtain woody plant materials is to transplant whole plants or dormant cuttings from adjacent undisturbed communities. A new edition of *A vegetative guide for Alaska*, soon to be published, will contain a significant amount of new information on use of woody plants in revegetation.

Continued ...

Zasada, J.C. and A.C. Epps. 1976. Continued

The table below, from *A vegetative guide for Alaska* (revised edition in press), list the trees and tall shrubs, intermediate shrubs, and ground covers recommended for the Alaska Interior. The soil groups listed in the second column of these tables are defined as follows: 1 - Soils and sites with few limitations; 2 - Soils and sites with limitations due to water-holding capacity; 3 - Soils and sites with severe limitation due to very low water-holding capacity or steep slopes; 4 - Soils and sites with moderate limitations due to excess moisture; 5 - Soils and sites with severe limitations due to excess moisture; and 6 - Soils and sites consisting of wet peat materials.

TREES AND TALL SHRUBS

(15 feet or more)

SPECIES FOR REVEGETATION	Adapted to Soil Groups	TYPE OF PROPAGATION Seed	Seedling & Transplants	Stem Cuttings	Root Cuttings
Larix laricina	1,4,5,6	X	X		
*Larix siberica**	1,2	X	X		
*Picea abies**	1,2,4	X	X		
Picea glauca	1,2,4	X	X		
Picea mariana	1,4,5,6	X	X		
Pinus contorta var. *latifolia**	1,2,4	X	X		
*Pinus sylvestris**	1,2	X	X		
Alnus tenuifolia	1,2,4,5	X**	X	X	
Betula papyrifera var. *humilis*	1,2,4,5	X	X		
Populus balsamifera	1,2,4	X	X	X**	X
Populus tremuloides	1,2,3,4	X	X		X
*Prunus padus**	1,2	X	X	X	
Salix alaxensis	1,2,4,5	X	X	X**	
Salix bebbiana	1,2,4,5	X	X	X**	
Salix scouleriana	1,2,4,5,6	X	X	X**	
Sorbus aucuparia	1,2		X	X	

* Exotic

** Recommended Method

Continued ...

Zasada, J.C. and A.C. Epps. 1976. Continued

INTERMEDIATE SHRUBS

(3-15 feet)

SPECIES FOR REVEGETATION	Adapted to Soil Groups	Seed	Seedling & Transplants	Stem Cuttings	Root Cuttings
Alnus crispa	1,2,4,5	X*	X		
Cornus stolonifera	1,4,5	X	X	X*	X
Elaeagnus commutata	1,2,3	X	X		X
Potentilla fruticosa	1,2,4,5	X	X		
Rosa acicularis	1,2,4,5	X	X	X	X
Rubus idaeus var. *strigosus*	1,2,4	X	X	X	X
Salix arbusculoides	1,4,5	X	X	X*	
Salix glauca	1,4,5	X	X	X*	
Salix lanata spp. *richardsonii*	1,4,5	X	X	X*	
Salix planifolia ssp. *pulchra*	4,5,6	X	X	X*	
Sheperdia canadensis	1,2	X	X		
Sorbus scopulina	1,2,4		X	X	
Spiraea beauverdiana	1,4,5,6	X	X	X	
Viburnum edule	1,2,4	X	X	X	

* Recommended Method

Continued ...

Zasada, J.C. and A.C. Epps. 1976. Continued

GROUNDCOVERS
(3 feet or less)

SPECIES FOR REVEGETATION	Adapted to Soil Groups	Seed	Seedling & Transplants	Stem Cuttings	Root Cuttings
Juniperus communis nana	1,2,3	X	X		
Juniperus horizontalis	1,2,3	X	X		
*Juniperus horizontalis douglasi**	1,2,3		X		
*Juniperus horizontalis plumosa**	1,2,3		X		
*Juniperus horizontalis procumbens**	1,2,3		X		
*Pinus mugo mughus pumilo**	1,2,3		X		
Andromeda polifolia	4,5,6	X	X		
Arctostaphylos alpina	1,2,3	X		X	
Arctostaphylos rubra	1,2,3,4	X		X	
Arctostaphylos uva-ursi	1,2,3	X		X	
Artemisia alaskana	1,2,3	X	X	X	
Artemisia frigida	1,2,3	X	X	X	
Betula nana	1,2,4,5	X	X		
Chamaedaphne calyculata	4,5,6	X			
Cornus canadensis	1,2,4	X	X**		X
Empetrum nigrum	1,2,4,5	X	X	X***	
Ledum decumbens	4,5,6	X	X		
Ledum groenlandicum	4,5	X	X		
Myrica gale	4,5,6		X		
Rhododendron lapponicum	1,2,4,5	X	X	X	
Ribes triste	1,2,4	X	X	X	
Rubus arcticus	1,4,5,6	X	X		X
Rubus chamaemorus	1,4,5,6	X	X		
Salix fuscesens	4,5,6	X	X	X***	
Salix reticulata	1,2,4,5	X	X	X***	
*Symphoricarpos orbiculatus**	1,2,3,4	X	X		X
Vaccinium uliginosum	1,2,4,5	X	X	X	
Vaccinium vitis-idaea	1,2,4,5	X	X**		

* Exotic ** Sod Method *** Recommended Method

1. ZIEMKIEWICZ, P.
2. 1974
3. Reclamation research methods on coal mine wastes with particular reference to species evaluation and assessment.
4. In: Proceedings of the Inaugural Meeting Canadian Land Reclamation Association, Crop Science Department, Ontario Agricultural College, University of Guelph, Guelph, Ontario, p 69-76
5. Original
6. a. British Columbia; Rocky Mountains

   b. Alpine, Southwestern Mackenzie, Southern Yukon; Overburden

7. Choice of species in a vegetation program is critical to its success or failure. Two methods that enable selection of herbaceous species are: (1) the evaluation of previously treated revegetation areas; and (2) the establishment of trial plots. The advantage of the first method is the chance to examine the long-term responses of species to a wide range of physical variables. This permits a qualitative assessment of species similar to that carried out for reclamation species in Pennsylvania and Indiana. Canada lacks such long-term reclamation efforts. Thus, the trial plot method, and quantification of performance in terms of slope, elevation, aspect, or soil chemical status, are the other alternatives generally used in Canada.

The trial plot method is currently used for reclamation research by Kaiser Resources in the East Kootenays, British Columbia. Aerial biomass data and soil nutrient analyses, as yet incomplete, indicate a strong segregation of species according to the various disturbed sites.

Because of the interim nature of this report, the only conclusion made is that future reclamation efforts, particularly in high-altitude areas of British Columbia, will depend on the availability of species capable of colonizing the harshest sites with minimum maintenance. Native and introduced species should be tested under rigorous conditions and certified on the basis of their durability.

1. ZIMMERMANN, R.C. and T.R. MOORE

2. 1974

3. Study of vegetation of asbestos mine wastes,Eastern Townships, Quebec.

4. Final report to the Environmental Control Committee, Quebec Asbestos Mining Association. Unpublished report. 41 p

5. Original

6. a. Quebec; Eastern Forest

   b. Southwestern Mackenzie, Southern Yukon; Tailings

7. From this final report on the study of vegetation of asbestos mine wastes in the asbestos belt of southeastern Quebec, a few of the principal findings and recommendations, as listed below, are of potential interest for revegetation programs on mine wastes in northern Canada.

1. The field trials of 1974 confirmed that an application of N,P,K at a rate of 1 kg/m^2 (4.5 short tons/acre) is essential for adequate plant growth on tailings; applications in excess of this rate bring no improvements or have detrimental effects, while applications below this rate result in stunted growth or no growth at all;

2. Additions of organic matter, whether manure or sawdust, are essential for the establishment of a vigorous, continuous plant cover; omission of organic matter can result in loss or in harmful concentrations of inorganic fertilizer;

3. On sloping tailings at angle of rest (30-40 deg), plant growth is impeded by loss of seed and inorganic fertilizer, and by the instability of the tailings, by both erosion and burial; however, a successful plant cover can be established on slopes provided organic matter is added at a rate of at least 4 kg/m^2 (18 short tons/acre), and the tailings are friable to a depth of at least 20 cm (3 in);

4. Heavy losses of inorganic fertilizer can occur from slopes with angles of less than 10 deg. if no organic matter is present;

5. The most difficult sites to vegetate are tailings at angle of rest and with either a surficial crust or an indurated/compacted layer at depths of less than 10 cm (4 in); on these sites, a continuous cover of grasses and legumes is not a practical objective for initial reclamation;

Continued ...

Zimmermann, R.C. and T.R. Moore. 1974. Continued

6. Seedlings of "weedy" species of trees such as aspen and paper birch can be planted on steep or indurated tailings more easily than grasses and legumes; these seedlings can be sustained with slow-release fertilizers buried in the tailings, but their long-term success is not yet assured;

7. It is estimated that a more realistic per acre cost of reclamation using the basic method ("high" N,P,K and organic matter) is in the $1,200-1,400 range; these cost estimates include an allowance for some initial maintenance, but do not consider economies of scale that might be achieved with a large-scale reclamation program;

8. It is recommended that a reclamation program assign different priority ratings to different waste areas, and that different reclamation methods be used to achieve the objectives on these different areas.

9. It is recommended that low-priority areas of tailings (remote or poorly visible) be reclaimed by means of inorganic fertilization and subsequent natural colonization by weeds and other local plants; cost of this method may be as low as $700-800 per acre;

10. It is recommended that long slopes or indurated tailings be reclaimed with seedlings of tolerant trees such as aspen, paper birch or pin-cherry and fed with slow-release fertilizers; per acre cost of this method is in the $700-900 range, but full commitment to this method should be deferred until several years' experience is gained with it on one or more acres;

11. It is recommended that high-priority areas (highly visible or near residential areas) be reclaimed with the basic method modified by the addition of small volumes of soil designed to "buffer" the tailings against uneven application of the basic treatment; per acre cost of this method is in the $860-1,270 range;

12. It is recommended that small, high-priority areas be reclaimed by burying the tailings under agricultural soil at least 15 cm (6 in) thick; per acre cost of this method varies from $900 to 1,400 depending on the volume of soil used and the need for anchoring this soil.

1. ZUFA, L.
2. 1971
3. A rapid method for vegetative propagation of aspens and their hybrids.
4. The Forestry Chronicle 47:36-39
5. Original
6. a. Ontario; Eastern Forest

   b. Southwestern Mackenzie, Southern Yukon; Overburden, Roads

7. Aspens typically regenerate by suckers, which are adventitious shoots formed on roots. This property of aspens has been used for vegetative propagation in several ways: (1) suckers with roots have been lifted from stands and used as transplants; (2) roots of a known tree have been used for root cuttings; and (3) green cuttings have been taken from herbaceous suckers. However, suckers of satisfactory quality and known origin seldom can be found in large quantities in stands. Green cuttings taken from young succulent suckers offer the best possiblity for vegetative propagation of aspens.

The steps taken for aspen propagation were as follows:

1. In the fall, parts of roots, 1 to 2 1/2 inches in diameter, were excavated from a tree and cut into 8-inch long sections.

2. These root cuttings were planted horizontally, a half-inch deep, in coarse sand in flats (12 x 8 x 6 inches) and kept in the greenhouse at temperatures between 60 and 90° F and humidities between 30 and 90%.

3. Suckering of these fall planted aspen root cuttings started 25 days after planting and continued for 5 months (root cuttings planted in spring started suckering in 12 days and continued for 3 months); since this suckering is most intense during the first 2 months (for either fall or spring planting) for practical purposes the root cuttings should be kept suckering for 2 months and then discarded; new root cuttings should be excavated and new sucker production started any time during the year.

4. Suckers were collected in a succulent stage, 2 to 4 days after their first appearance, when they were 1 1/2 to 4 inches long; the entire sucker was removed including the etiolated base adjacent to the root cutting.

5. Each sucker was planted 1 to 1 1/2 inches deep in a slit polystyrene tube (3/4 x 3 inches) containing a rooting medium of 2 inches of coarse acid sand over a 3/4 inch layer of black loam.

Continued ...

Zufa, L. 1971. Continued

6. The flats with suckers in tubes were kept in a clear polyethylene tent with a bottom layer of wet peat moss to maintain humid conditions, until rooting occurred; for the fall experiment the tent was placed in the coolest part of the greenhouse (temperature 65 to 75° F and humidity 60 - 70%); for the spring experiment the tent was set up in a growth chamber for better control of temperature (68 - 70° F) and humidity (70 - 75%).

7. The suckers rooted 8 to 21 days after planting; in the fall experiment 84% of the suckers rooted and in the spring 48% rooted.

8. Rooted suckers in tubes can be outplanted without risk of breaking the roots or losing the plant.

This method allows for fast initial propagation of a tree. In this experiment, more than 200 suckers were produced by only 4 root cuttings of a tree in a period of just one month.

This method of propagation could be carried out in a simpler way in the nursery by taking advantage of the aspen's suckering capacity. The rooted suckers of each clone could be planted in a separate nursery compartment. They should be allowed to develop to a desired size, then lifted and outplanted. More suckers would then develop from the roots left in the soil. During the growing season the developing suckers should be thinned to a desired spacing and number. Such propagation could continue for a number of years, giving several generations of suckers. Mass propagation of the best aspen clones could be thus solved in a very practical and inexpensive way.

SUBJECT INDEX

This subject index is not arranged alphabetically. It is organized according to an approximate sequence of steps that one would follow during a program of assisted revegetation.

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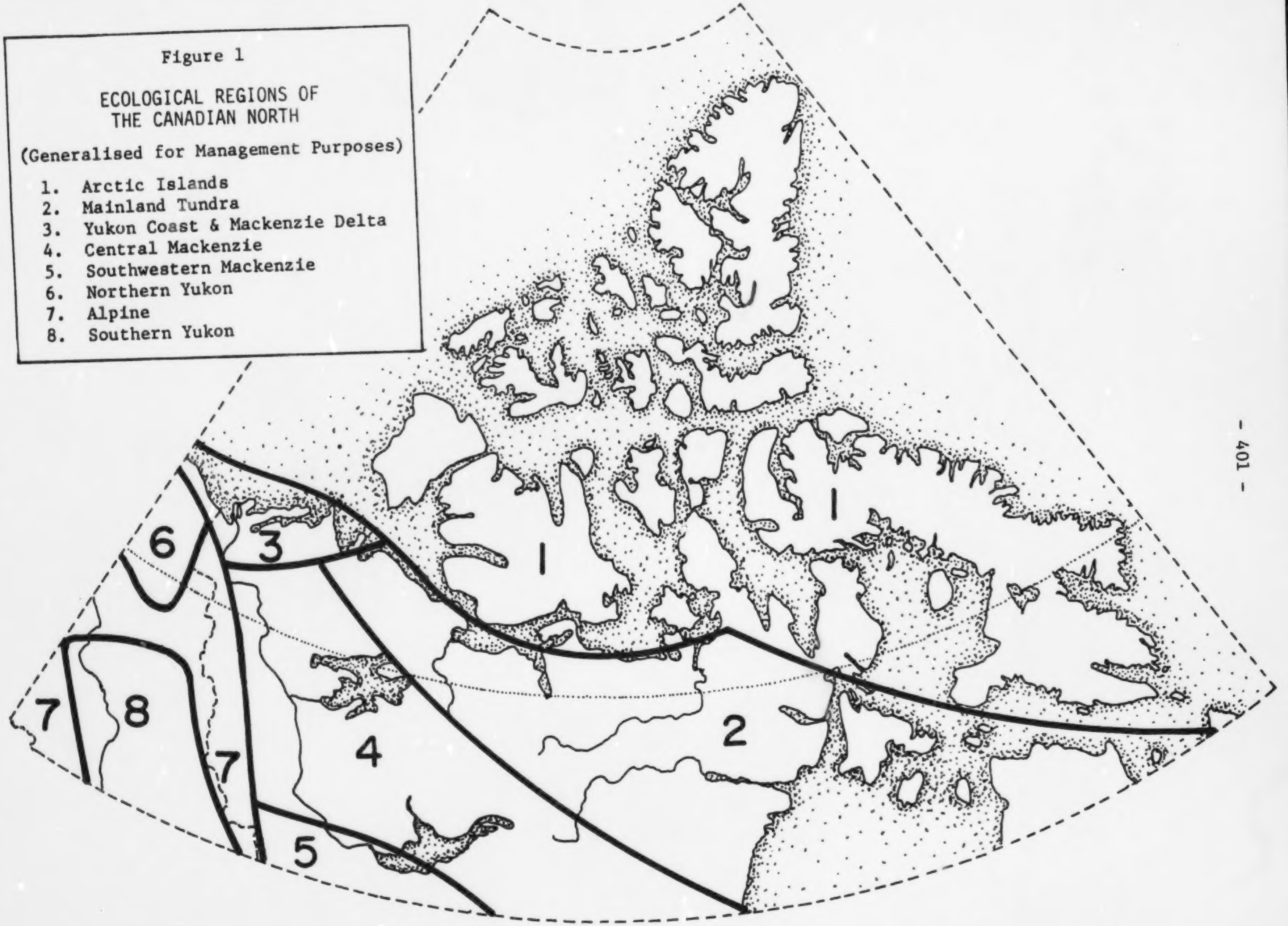

Figure 1

ECOLOGICAL REGIONS OF
THE CANADIAN NORTH

(Generalised for Management Purposes)

1. Arctic Islands
2. Mainland Tundra
3. Yukon Coast & Mackenzie Delta
4. Central Mackenzie
5. Southwestern Mackenzie
6. Northern Yukon
7. Alpine
8. Southern Yukon

INDEX OF APPLICABILITY TO NORTHERN AREAS

This is an index of northern disturbed areas to which existing revegetation knowledge is thought to be applicable; it is not an index of areas in the North from which revegetation information has been collected.

In this index, the Northwest Territories and Yukon are divided into eight ecologically distinct regions, as shown in Figure 1 of this report. For each region, three general kinds of disturbances related to mining (overburden, roads, and tailings) are recognized. For purposes of this index, roads include any other disturbances that involve only surface disruption of drainage, vegetation, organic matter and mineral soil, such as sites for exploratory diamond drilling or plant sites. Overburden is meant to include more substantial disturbances below the mineral soil horizons and could include waste rock, adit wastes, coal reject dumps, spoil piles, and material excavated from exploration trenches.

The index numbers below identify the pages in this bibliography that contain references of most use to someone interested in revegetation of a particular kind of disturbed site (overburden or road or tailings) in a particular region of the Yukon or Northwest Territories. For example, someone interested in revegetation of overburden in the Arctic Islands may find useful information or ideas on various pages in this bibliography, but the references of most relevance and the ones that should be checked first are the page numbers listed for overburden in the Arctic Islands region (pages 9, 10, 15, 17, 209). In this example it will be noted that these listed references are not necessarily a description of revegetation of overburden in the Arctic Islands; they are simply the sources of information that were judged to be most applicable to revegetation problems on overburden surfaces in that region.

The first part of this index lists sources of information that were thought to be useful throughout the Yukon and Northwest Territories rather than being specific to any one of the eight regions.

1. SOURCES OF REVEGETATION INFORMATION FOR CONSIDERATION THROUGHOUT THE YUKON AND NORTHWEST TERRITORIES -

1.1 OVERBURDEN - 2, 6, 12, 43, 101, 102, 128, 161, 170, 173, 207, 236, 254, 256, 273, 280, 291, 292, 300, 310, 314, 328, 360

1.2 ROADS - 6, 12, 101, 102, 161, 170, 233, 236, 254, 256, 291, 292, 310, 314, 328, 358, 360

1.3 TAILINGS - 4, 12, 42, 43, 79, 81, 90, 101, 102, 128, 236, 254, 256, 272, 280, 292, 310, 314, 328, 360

2. SOURCES OF REVEGETATION INFORMATION THOUGHT TO BE MOST APPLICABLE TO THE ARCTIC ISLANDS REGION (area 1 on map) -

2.1 OVERBURDEN - 9, 10, 15, 17, 209

2.2 ROADS - 9, 10, 15, 17, 31, 37, 39, 152, 209, 249

2.3 TAILINGS - nil

3. SOURCES OF REVEGETATION INFORMATION THOUGHT TO BE MOST APPLICABLE TO THE MAINLAND TUNDRA REGION (area 2 on map) -

3.1 OVERBURDEN - 171, 318, 320

3.2 ROADS - 249, 371, 373, 379, 382

3.3 TAILINGS - 171, 221, 318, 320

4. SOURCES OF REVEGETATION INFORMATION THOUGHT TO BE MOST APPLICABLE TO THE YUKON COAST AND MACKENZIE DELTA REGION (area 3 on map) -

4.1 OVERBURDEN - 104, 177, 178, 179, 184, 187, 188, 190, 199, 217, 258, 259, 260, 311, 346

4.2 ROADS - 35, 37, 39, 50, 52, 56, 65, 69, 71, 73, 75, 104, 116, 118, 140, 141, 144, 145, 149, 157, 177, 178, 179, 184, 187, 188, 190, 199, 213, 214, 217, 249, 257, 258, 259, 260, 261, 264, 278, 288, 311, 313, 346, 365, 367, 369, 371, 373, 379, 382

4.3 TAILINGS - nil

5. SOURCES OF REVEGETATION INFORMATION THOUGHT TO BE MOST APPLICABLE TO THE CENTRAL MACKENZIE REGION (area 4 on map) -

5.1 OVERBURDEN - 104, 177, 178, 179, 184, 187, 188, 190, 199, 217, 258, 259, 260, 294, 311, 318, 320, 346, 384

5.2 ROADS - 52, 56, 65, 69, 71, 73, 75, 104, 116, 118, 141, 145, 149, 177, 178, 179, 184, 187, 188, 190, 199, 217, 258, 259, 260, 264, 278, 294, 311, 313, 346, 371, 373, 377, 384

5.3 TAILINGS - 174, 221, 262, 294, 311, 318, 320, 384

6. SOURCES OF REVEGETATION INFORMATION THOUGHT TO BE MOST APPLICABLE TO THE SOUTHWESTERN MACKENZIE REGION (area 5 on map) -

6.1 OVERBURDEN - 59, 68, 77, 84, 85, 88, 92, 96, 99, 100, 104, 106, 107, 109, 114, 133, 134, 136, 159, 177, 178, 179, 180, 182, 184, 186, 187, 188, 190, 194, 196, 198, 199, 200, 201, 202, 205, 211, 216, 217, 218, 224, 231, 245, 251, 258, 259, 260, 263, 268, 270, 272, 276, 284, 294, 296, 299, 301, 308, 311, 315, 318, 320, 322, 324, 326, 334, 337, 340, 344, 346, 354, 356, 363, 364, 377, 384, 388, 391

6.2 ROADS - 33, 48, 65, 69, 71, 73, 75, 92, 99, 100, 104, 106, 107, 116, 118, 121, 125, 145, 177, 178, 179, 180, 182, 184, 186, 187, 188, 190, 194, 196, 198, 199, 200, 201, 202, 216, 217, 218, 227, 258, 259, 260, 278, 284, 294, 311, 313, 334, 337, 340, 344, 346, 348, 351, 356, 371, 373, 384, 391

6.3 TAILINGS - 27, 29, 61, 134, 136, 159, 169, 174, 205, 221, 224, 225, 240, 248, 250, 262, 263, 266, 268, 270, 275, 284, 294, 303, 306, 311, 315, 318, 320, 353, 384, 389

7. SOURCES OF REVEGETATION INFORMATION THOUGHT TO BE MOST APPLICABLE TO THE NORTHERN YUKON REGION (area 6 on map) -

7.1 OVERBURDEN - 104, 219, 258, 259, 260, 290, 294, 311, 346, 384

7.2 ROADS - 41, 50, 104, 138, 157, 219, 258, 259, 260, 264, 278, 290, 294, 311, 313, 346, 371, 373, 377, 384

7.3 TAILINGS - 294, 311, 384

8. SOURCES OF REVEGETATION INFORMATION THOUGHT TO BE MOST APPLICABLE TO THE ALPINE REGION (area 7 on map) -

8.1 OVERBURDEN - 1, 22, 25, 34, 47, 84, 85, 88, 93, 96, 97, 98, 104, 109, 111, 119, 123, 124, 133, 134, 136, 151, 155, 219, 229, 234, 237, 238, 241, 242, 243, 252, 276, 283, 286, 290, 294, 296, 309, 311, 346, 349, 356, 388

8.2 ROADS - 20, 25, 34, 50, 55, 93, 94, 97, 98, 104, 130, 131, 138, 155, 219, 238, 241, 243, 252, 283, 290, 294, 309, 311, 346, 349, 356, 362, 364

8.3 TAILINGS - 25, 34, 93, 134, 136, 175, 238, 294, 311

9. SOURCES OF REVEGETATION INFORMATION THOUGHT TO BE MOST APPLICABLE TO THE SOUTHERN YUKON REGION (area 8 on map) -

9.1 OVERBURDEN - 45, 54, 59, 62, 63, 68, 77, 84, 85, 88, 92, 96, 99, 100, 104, 106, 107, 109, 114, 123, 133, 134, 136, 153, 154, 159, 180, 182, 186, 194, 196, 198, 200, 201, 202, 203, 205, 211, 216, 217, 218, 219, 224, 231, 245, 251, 258, 259, 260, 263, 268, 270, 272, 275, 276, 284, 290, 294, 296, 299, 301, 308, 309, 311, 315, 318, 320, 322, 324, 326, 334, 337, 340, 344, 346, 354, 356, 363, 364, 384, 388, 391

9.2 ROADS - 33, 41, 45, 48, 92, 99, 100, 104, 106, 107, 113, 121, 125, 138, 157, 180, 182, 186, 194, 196, 198, 200, 201, 202, 203, 216, 217, 218, 219, 227, 258, 259, 260, 284, 290, 294, 309, 311, 334, 337, 340, 344, 346, 348, 351, 356, 371, 373, 377, 384, 391

9.3 TAILINGS - 13, 27, 29, 61, 132, 134, 136, 159, 169, 174, 205, 221, 224, 225, 240, 248, 250, 262, 263, 266, 268, 270, 284, 294, 303, 306, 311, 315, 318, 320, 353, 384, 389